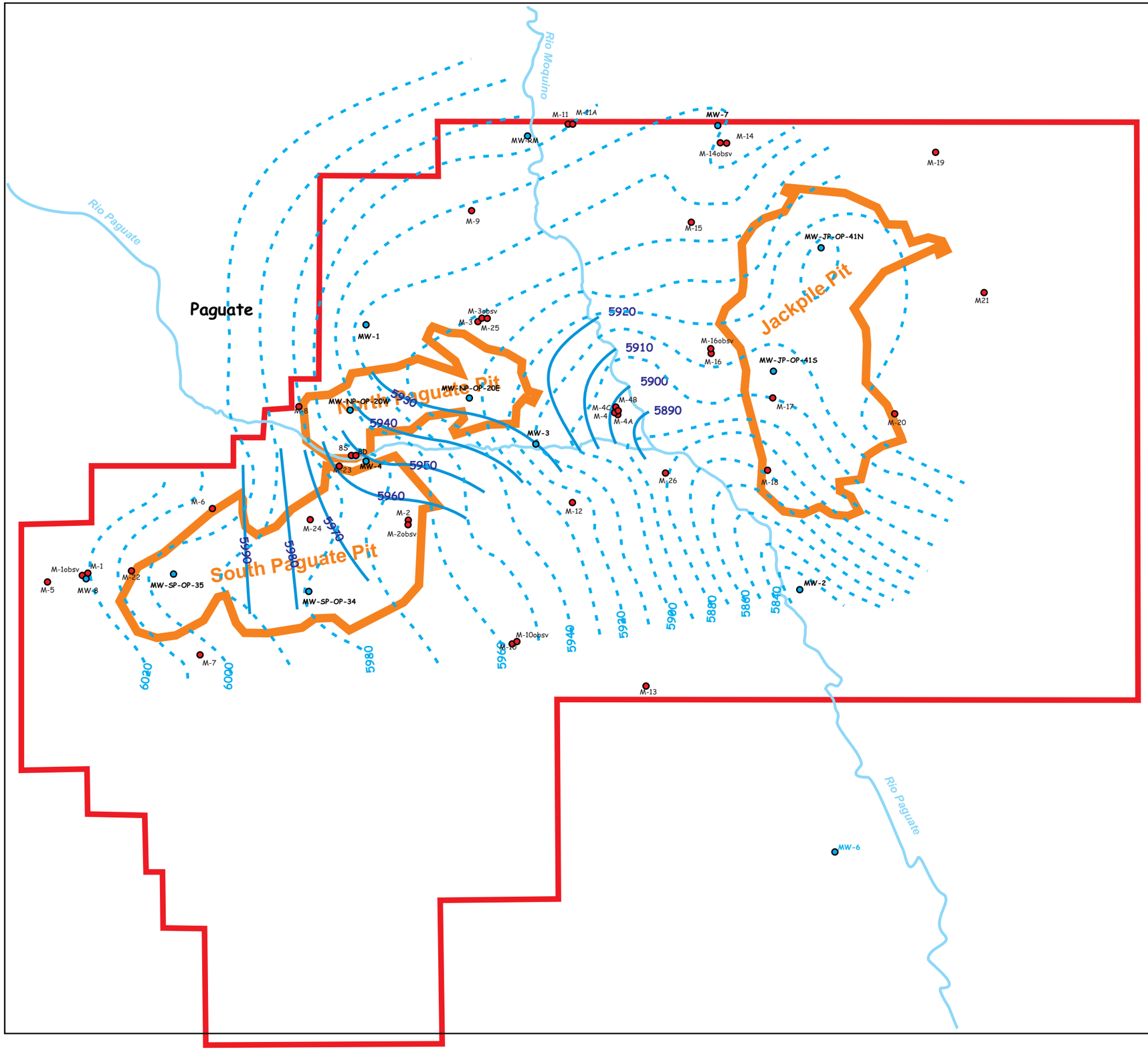


Jackpile-Paguate Mine Site

Expanded Site Inspection

Revised Conceptual Site Model

Legend:

- Site Outline
- Rivers
- Pits
- Pre-Remedial (M-Series) Wells
- Post-Remedial (MW-Series) Wells
- 1979 Groundwater Contours (HydroSearch)
- 2011 ESI Groundwater Contours (this work)

Elevations in feet above Mean Sea Level

N W E S

Scale In Miles

0 0.2 0.4 0.6 0.8 1.0

NEW MEXICO

Data Sources: Hydro-Search, 1979
Anaconda, 1983
Image Source: GoogleEarth Pro 2011

TDD: TO-0019-10-11-01

USEPA REGION 6
START - 3

FIGURE 5
2011 ESI Groundwater Surface Contours
JACKPILE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002760

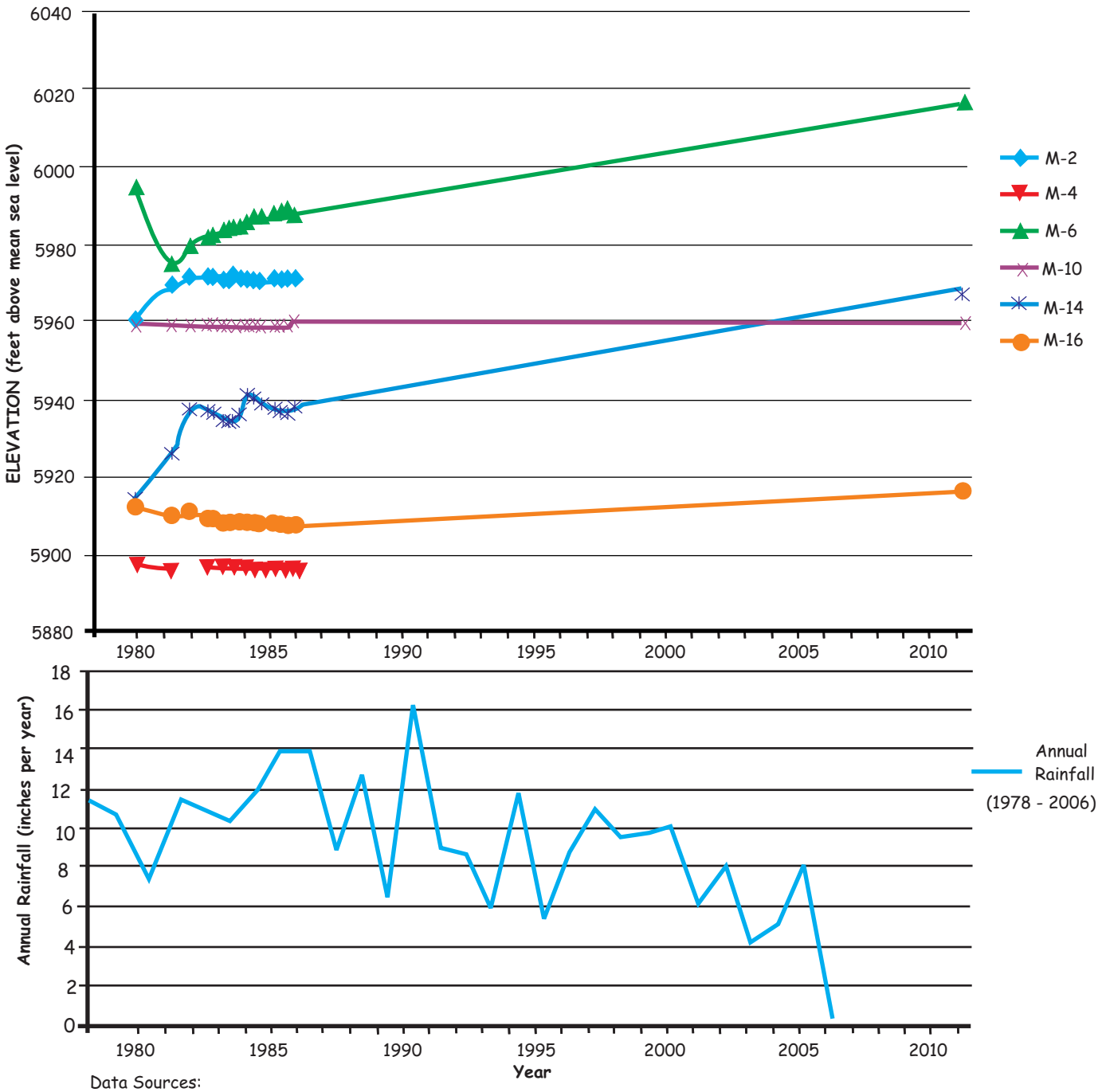
Surface water elevation was not taken into account when the contours were drawn, however the groundwater contours fare consistent with surface water flow.

Table 1 shows the groundwater elevation measurements for the eleven pre-remedial wells for which 1980 and 2011 data are available. Groundwater elevations measured in 2011 are higher than 1980 in all of the wells. The wells that are up-gradient of the pits have risen substantially (16 to 66 feet) since 1980, while those down-gradient of the pits differed in elevation by about a half a foot. Overall, the 2011 groundwater contours closely resemble the 1979 contours, where they overlap in the southwestern portion of the site.

Quarterly groundwater elevation data are available for only six wells over the period 1980 to 1986. These data are graphed as a function of time in Figure 6. Groundwater elevations for the four wells measured in 2011 are also plotted; M-2 and M-4 were not found during the field activities and may have been buried during remediation. Groundwater at M-2 (which is/was located in the South Paguate pit) shows a rapid rebound from 1980 to 1982, and subsequently levels off for the duration of the monitoring data. M-6, which is located on the northwestern edge of the South Paguate pit, show a significant drop from 1980 to 1982, then a steady increase from 1982 to 1986. M-14 shows a pronounced increase in water level from 1980 to 1982, then a bi-annually-influenced increase from 1982 to 1986. M-16 drops steadily from the 1980 to 1986, but has increased to over 4 feet above the 1980 level by 2011.

There is very little change in the levels of M-4 and M-10 over the period of measurement; groundwater elevation at these locations appears to be moderated by some hydrologic process such as dispersive (lateral) flow. The M-4 cluster of four wells is/was located between, and just above the confluence of, Rios Paguate and Moquino; it is very likely that levels in these wells would be directly affected by surface water. M-10, however, is farther away from surface water sources, on a mesa to the southeast of the South Paguate Pit. The M-10 well is constructed in the Jackpile Sandstone, which outcrops to the northeast, east, southwest, west, and southeast in the walls of the mesa. It is possible that groundwater in the vicinity of M-10 is cut off from the main groundwater system, or moderated by seepage where the Jackpile Sandstone outcrops in the walls of the mesa.

The 16- to 66-foot increase in the groundwater elevations in the upgradient wells (M-1, -6, -7, -8, -9, and -14) from 1980 to 2011 is likely attributable to the backfilling of the pits and subsequent rebound of the water table. The rebound was predicted by Dames and Moore (1983); however, the estimated rebound times for the North Paguate, South Paguate, and Jackpile pits were calculated at 30, 150, and 300 years respectively. After 30 years, groundwater in the North Paguate pit has not reached its predicted equilibrium elevation of 5979 feet above mean sea level. Groundwater in the South Paguate pit is close to, if not exceeding the predicted equilibrium elevation of 5982 feet above mean sea level. Groundwater level in the Jackpile pit is about twenty feet below the predicted equilibrium elevation of 5929 feet above mean sea level. Dames and Moore's calculations were based on a draft Site Remedial Plan, and it is unclear how much of the report recommendations for slowing the flow of groundwater into the North Paguate pit, not to mention final backfill elevations for the other pits, were included in the final remedial effort.



Data Sources:

Historical groundwater elevations taken from Anaconda Data Transmittals (Anaconda, 1983, 1985, 1986).

May 2011 groundwater elevations collected during the 2011 ESI sampling event.

Annual rainfall data culled from the Western Regional Climate Center for Laguna, New Mexico (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nmlagu).

TDD: TO-0019-10-11-01

USEPA REGION 6 START - 3 PROJECT NO. 20406.012.019.0603.01 July 2011	**Jackpile-Paguate Mine Site Expanded Site Inspection Revised Conceptual Site Model**	**Historical Groundwater Elevation Plots**	**Figure 6**

350002762

2.5 Surface-Water/Aquifer Interaction

Hydro-Search (1979) used groundwater and surface water elevation data, as well as qualitative field observations, to conclude that Rios Paguate and Moquino lose water to the Alluvial Aquifer in the up-gradient areas to a point approximately 1500 feet above their confluence. Below this point (approximately 5925 feet above mean sea level), the river system receives water from the Alluvial Aquifer. The USGS (1985) confirmed this observation through its own calculations, using the same data set. A similar study conducted by Hydro-Search in July 1981, during "a period of high evapotranspiration," indicated that the area near the confluence loses water, suggesting a seasonal variation is the gain/loss of the river through this area. No detailed study to date has shown whether this is a regular, or seasonal, variation.

Hydrologic models by Dames and Moore (1983) and the USGS (1985) predict that surface water should be in intimate contact with groundwater. The hydraulic coefficient of the alluvium is 23 feet per day at the confluence of Rios Paguate and Moquino (USGS 1983), and should be even higher in areas where the alluvium has been replaced by overburden and tailings.

Figure 7 shows the location of a series of geologic cross sections through the Jackpile-Paguate Mine site. The cross sections are interpreted from boring logs, USGS geologic quadrangles, descriptions and historical elevations from the various hydrologic reports described above, as well as groundwater elevations and field measurements taken during the 2011 ESI field event. Thicknesses of the Jackpile Sandstone and other units are derived from geologic logs, where available, as well as measurements from USGS geologic quads. The locations of faults and fold structures in the bedrock are also interpreted from these sources. Geologic logs were not available for the post-remedial wells, so geologic units are interpolated from data at adjacent sources, where possible.

2.5.1 1979 Data Cross Sections

Cross sections A-A' and B-B' (Figure 8) are compiled entirely from the 1979 (Hydro-Search) data set and represent the surface water and groundwater conditions measured in March 1979. The well locations are taken from a figure in the report and are approximate. The wells are numbered differently from the M-series wells; however, it is possible that some of the 1979 well set (identified as "Test Well Nos. 1 – 10") may have been re-named. Some of the 1979 well locations are close to the locations of M-series wells. The locations and designations are kept separate in this Conceptual Site Model in order to limit speculation.

Cross section A – A' shows that groundwater elevations are lower than Rio Paguate in the vicinity of Test Well #10, but higher that Rio Paguate at point A'. This means that Rio Paguate is losing water to groundwater in the western half of the cross section, while gaining water from groundwater in the eastern half.

Jackpile-Paguate Mine Site

Expanded Site Inspection

Revised Conceptual Site Model

Legend:

- Site Outline
- Rivers
- Pits
- Pre-Remedial (M-Series) Wells
- Post-Remedial (MW-Series) Wells
- Cross Section Line (A – A')

Elevations in feet above Mean Sea Level

Scale In Miles: 0 0.2 0.4 0.6 0.8 1.0

N W E S

NEW MEXICO

Data Sources: Hydro-Search, 1979
Anaconda, 1983
Image Source: GoogleEarth Pro 2011

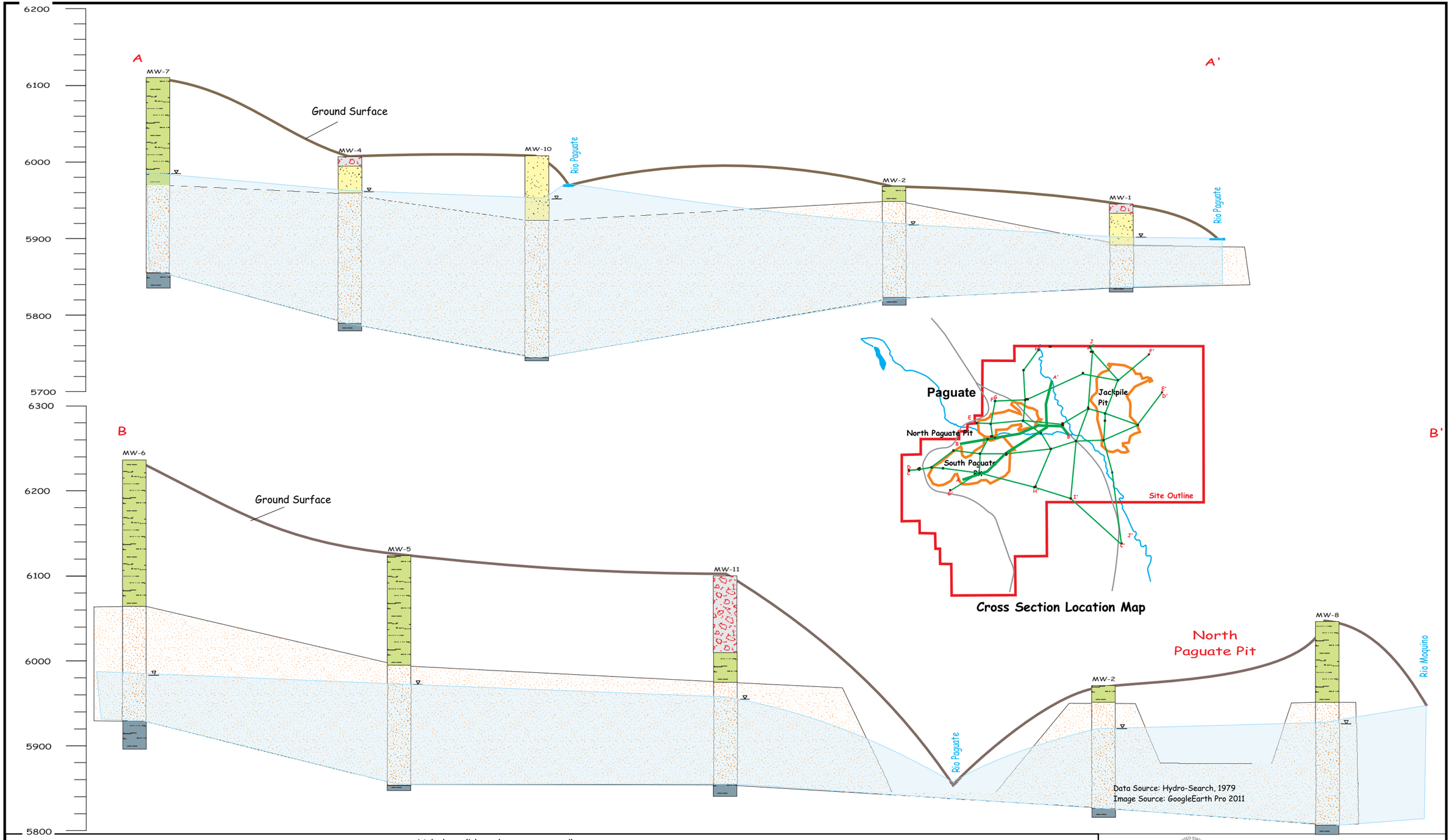
TDD: TO-0019-10-11-01

USEPA REGION 6
START - 3

FIGURE7
Cross Sections Locations Guide
JACKPILE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002764



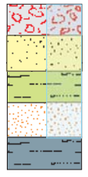
Cross Section Location Map

Data Source: Hydro-Search, 1979
Image Source: GoogleEarth Pro 2011

Data Used to Compile Cross Sections Are From Hydro-Search, 1979
See Figure 4 for Cross Section Locations

Vertical Exaggeration is approximately 1:12

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01



Lithology (blue where saturated):
Fill (Mine Waste)
Quaternary Alluvium
Cretaceous Units (undifferentiated)
Jurassic Jackpile Formation
Jurassic Bushy Branch Member

Horizontal Scale
In feet
0 500 1000 2000 3000

USEPA REGION 6
START - 3

FIGURE 8
GEOLOGIC CROSS SECTIONS A-A' and B-B'
JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002765

350002765

Cross section B – B' similarly shows that Rio Paguate is lower than adjacent groundwater elevations, hence gaining water where the section crosses the river. Rio Moquino is higher than nearby groundwater elevations, and is thus, losing water to the aquifer.

For both cases where the stream is shown to be gaining water, there is typically no more than about 5 feet of difference in elevation between the stream and nearest groundwater. The observation from the July 1981 measurements that Rios Paguate and Moquino are shown to lose water during the summer months (Hydro-Search, 1981) would only require modest seasonal depression of the local aquifer.

2.5.2 Cross Sections Using Current Data

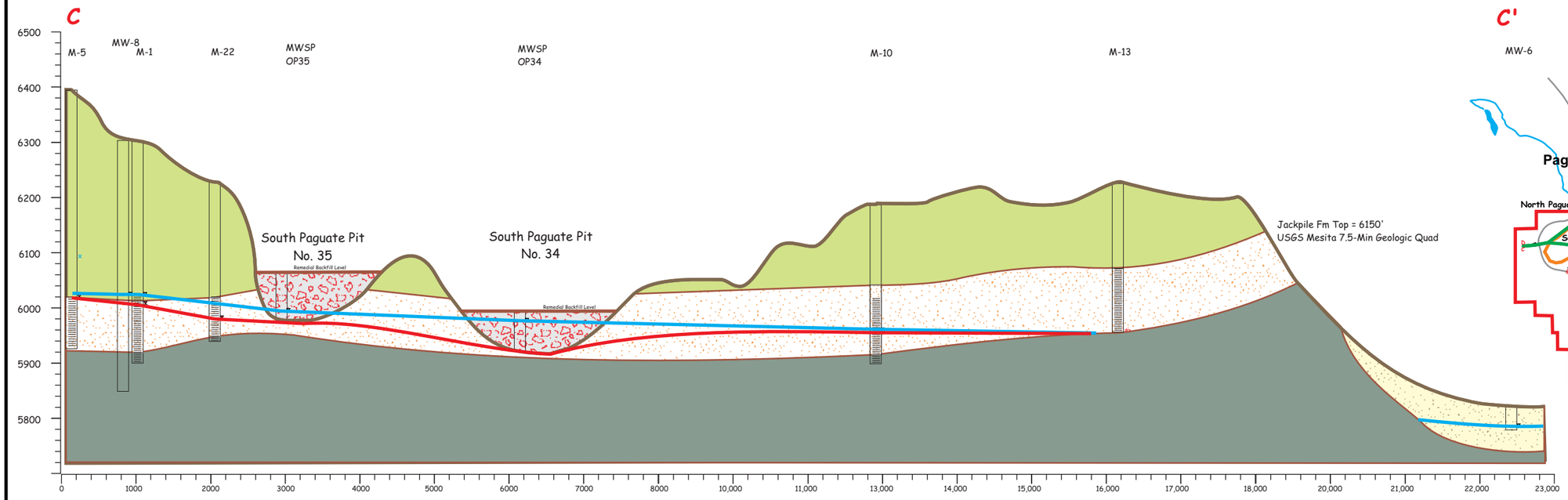
The west-east cross sections are presented in Figures 9 and 10. The four cross sections represent slices through the geologic material and hydrologic reservoirs of the site. Groundwater elevation data from 1980 (Hydro-Search 1981) and 2011 (May 2011 ESI event) are plotted in red and blue, respectively. In the pit areas, 1980 elevations are assumed to be at the base of the pit, or below, since Anaconda was likely managing water levels in the pits by pumping water to holding ponds during this period. The 2011 elevations in the pits are represented by measurements taken from the post-remedial pit wells.

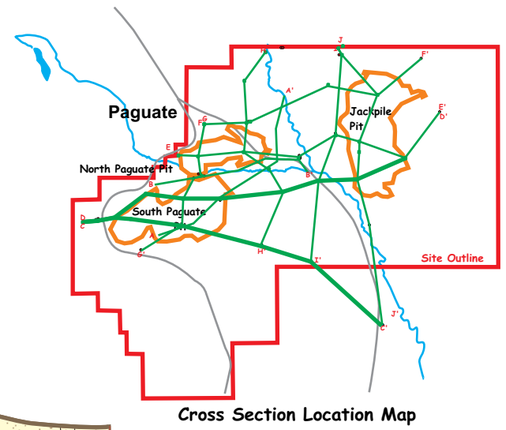
The north-south cross sections are presented in Figures 11 and 12. These cross sections, G-G', H-H', I-I' and J-J', were constructed in a similar manner to the west-east cross sections, using the same references and methods.

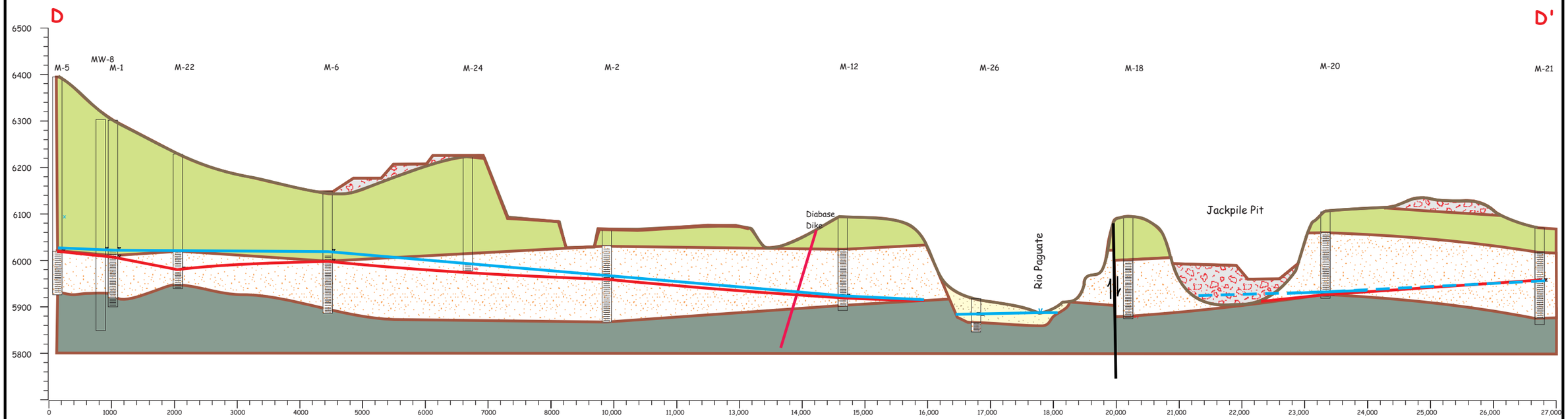
The Bushy Basin Member is considered an aquitard in these cross sections; however, several discontinuous sand lenses have been described in the literature (USGS 1984, Dames and Moore, 1983). Because the unit is generally considered to have a significantly lower hydraulic conductivity than the Jackpile Sandstone, groundwater contours are not extrapolated into the Bushy Basin. For example, groundwater is not interpreted to flow from M-13 to MW-6 in cross section C-C', or from M-12 to M-26 in cross section D-D'. This means that the Alluvial Aquifer and the Rio Paguate are possibly out of communication with Jackpile groundwater at M-26, and certainly by the time surface and groundwater reach MW-6.

Some of these sand layers are water-bearing and resemble the Jackpile Sandstone. Wells MW-5 and M-26 are logged as completed in Jackpile Sandstone, but are most likely completed in one of these minor sand lenses of the Bushy Basin Member. This becomes obvious when viewed in cross sections C-C' (where MW-5 is completed near MW-6) and D-D'; in both cases, the wells are screened at elevations below where the Jackpile Sandstone is projected on the cross section.

The cross sections show how depressed groundwater conditions in the pits are likely responsible for the lower groundwater levels measured during the 1980s, and the subsequent rebound is likely due to the backfilling of the pits. As part of the remedial effort, protore, tailings, and waste rock were placed in the pits to depths of 30 to 100 feet. Groundwater levels have infiltrated the backfilled pits by over 40 feet in some areas, which has likely somewhat restored the hydraulic head in the adjacent Jackpile Sandstone.







Data used to compile cross sections are from HydroSearch, 1981; USGS 1963; USGS, 1984; Anaconda, 1983, 1985, 1986, and this work.

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01

Lithology
- Fill (Mine Waste)
- Quaternary Alluvium
- Cretaceous Dakota Formation
- Jurassic Jackpile Formation
- Jurassic Bushy Branch Member

- Groundwater (2011)
- Groundwater (1980)
- Fault (USGS, 1963)
- Diabase Dike (USGS, 1963)

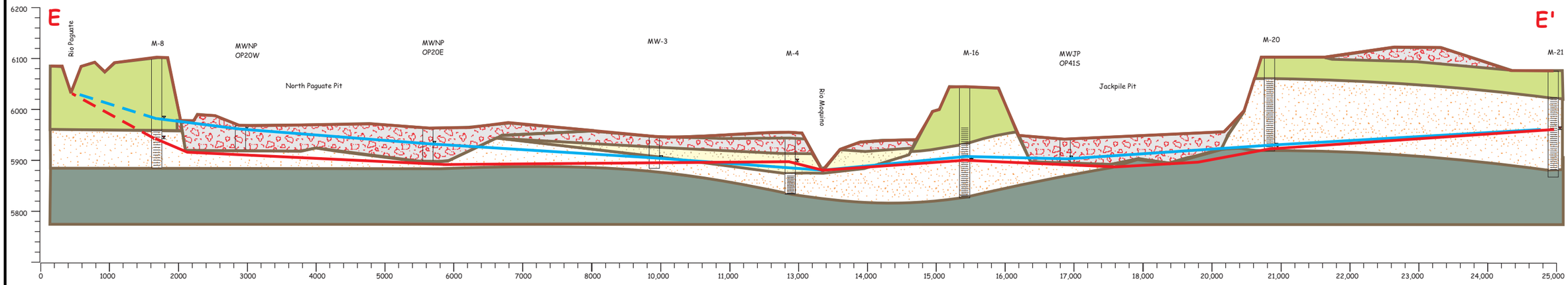
USEPA REGION 6
START - 3

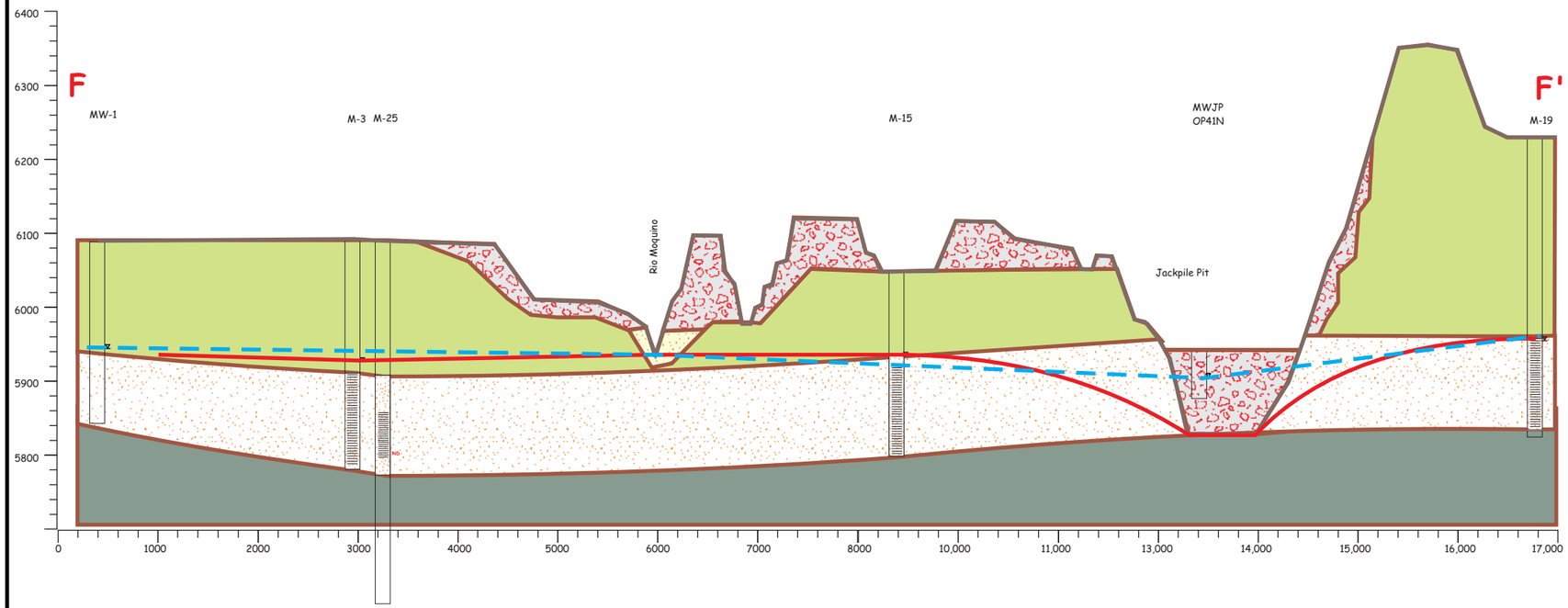
FIGURE 9
GEOLOGIC CROSS SECTIONS C-C' and D-D'
THROUGH THE JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

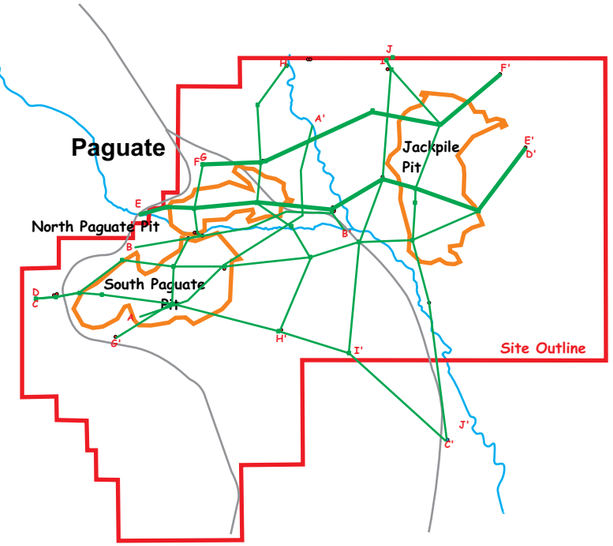
DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002767

350002767







Cross Section Location Map

Data used to compile cross sections are from HydroSearch, 1981; USGS 1963; USGS, 1984; Anaconda, 1983, 1985, 1986, and this work.

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01

Lithology
- Fill (Mine Waste)
- Quaternary Alluvium
- Cretaceous Formations (undifferentiated)
- Jurassic Jackpile Formation
- Jurassic Bushy Branch Member

- Groundwater (2011)
- Groundwater (1980)
- Fault (USGS, 1963)
- Diabase Dike (USGS, 1963)

NEW MEXICO

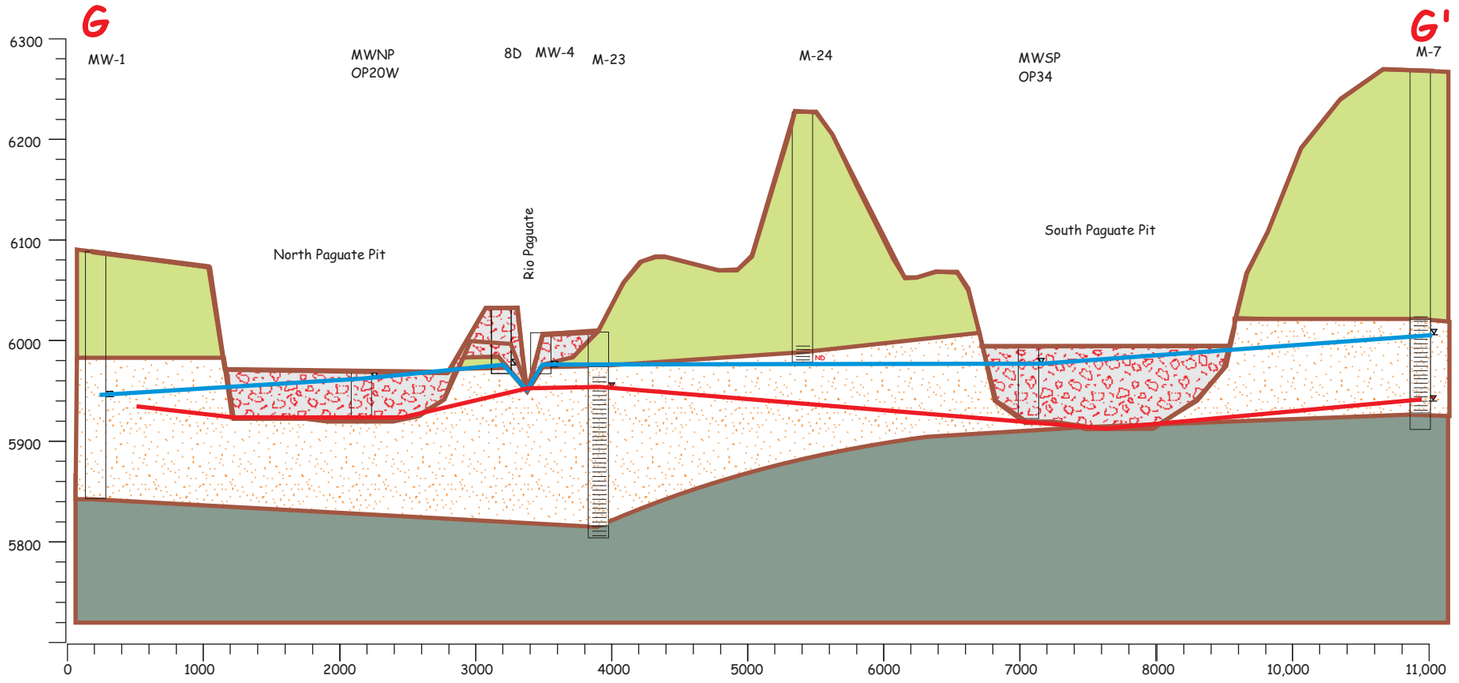
USEPA REGION 6
START - 3

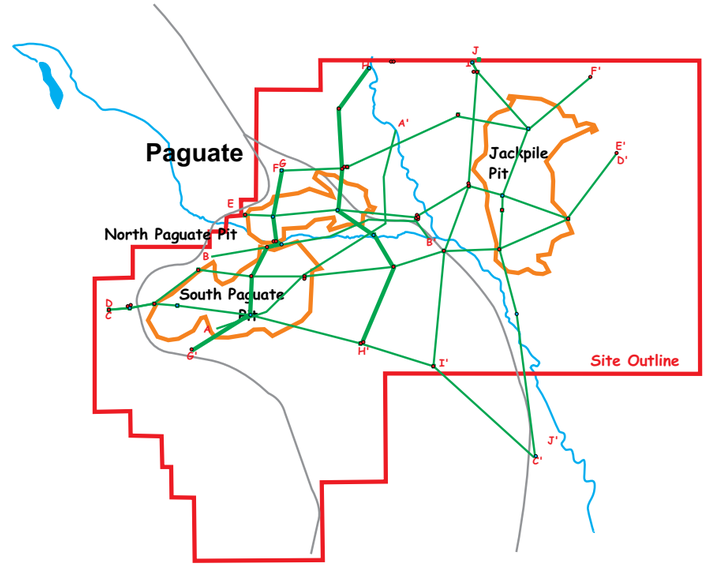
FIGURE 10
GEOLOGIC CROSS SECTIONS E-E' and F-F'
THROUGH THE JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

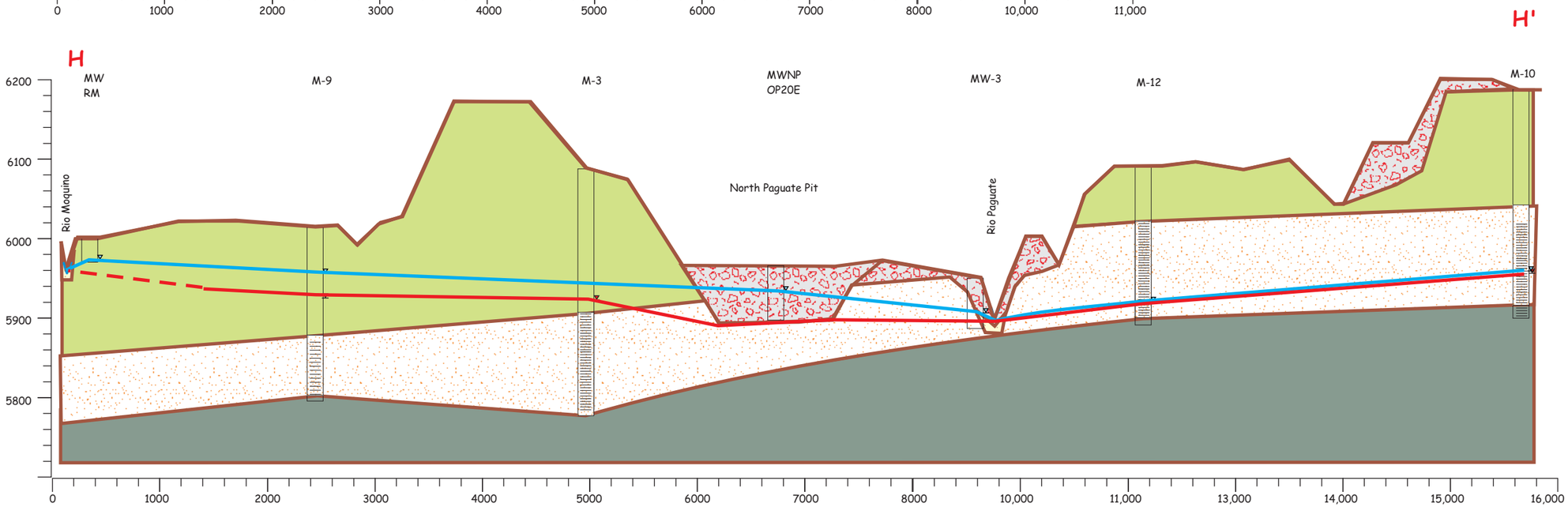
350002768

350002768





Cross Section Location Map



Data used to compile cross sections are from HydroSearch, 1981; USGS 1963; USGS, 1984; Anaconda, 1983, 1985, 1986, and this work.

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01

Lithology
- Fill (Mine Waste)
- Quaternary Alluvium
- Cretaceous Formations (undifferentiated)
- Jurassic Jackpile Formation
- Jurassic Bushy Branch Member

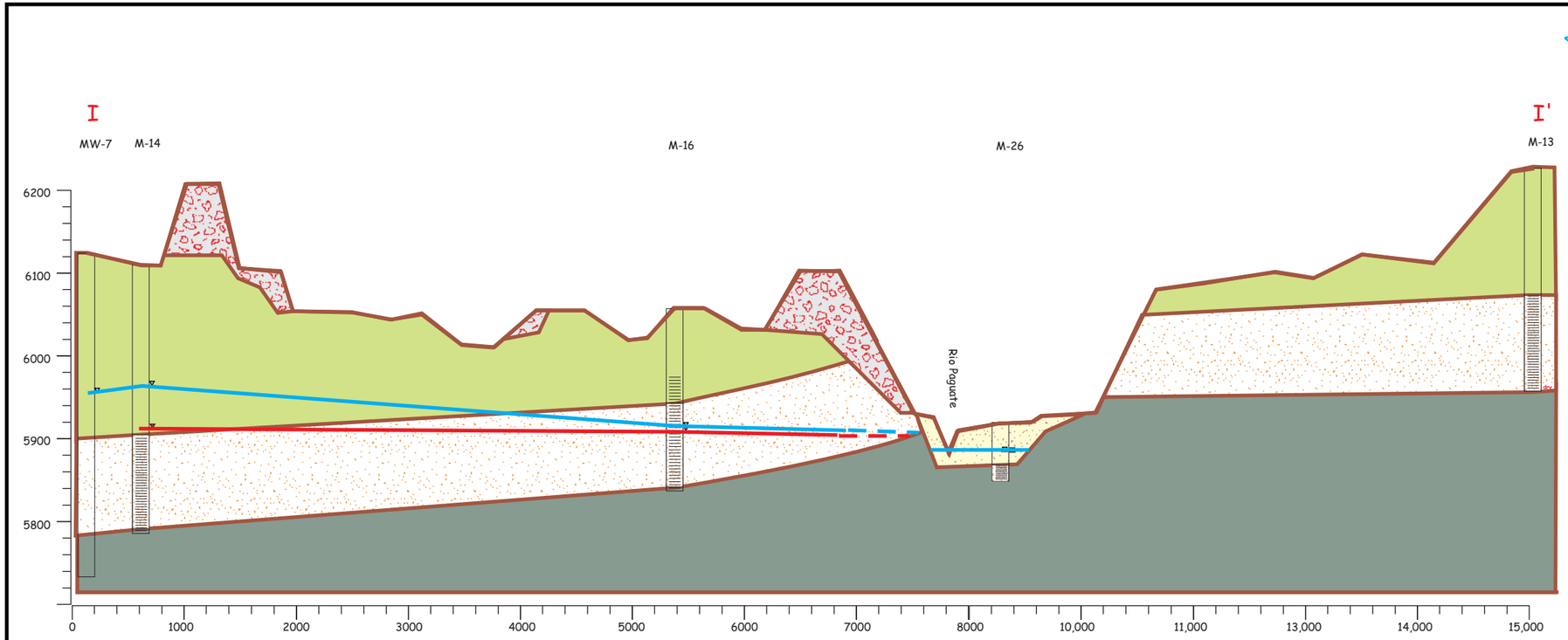
- Groundwater (2011)
- Groundwater (1980)
- Fault (USGS, 1963)
- Diabase Dike (USGS, 1963)

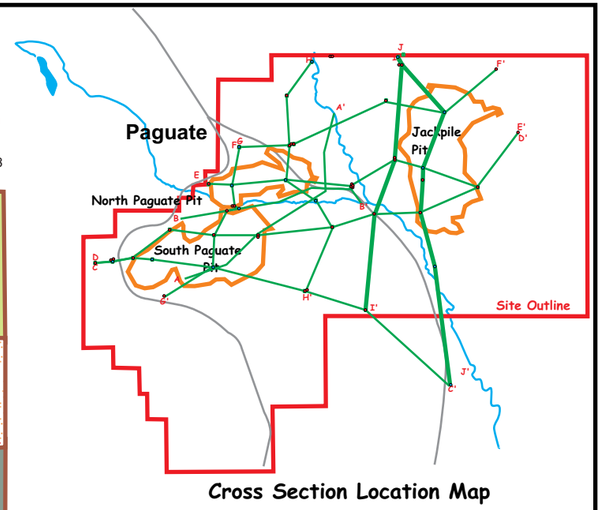
USEPA REGION 6
START - 3

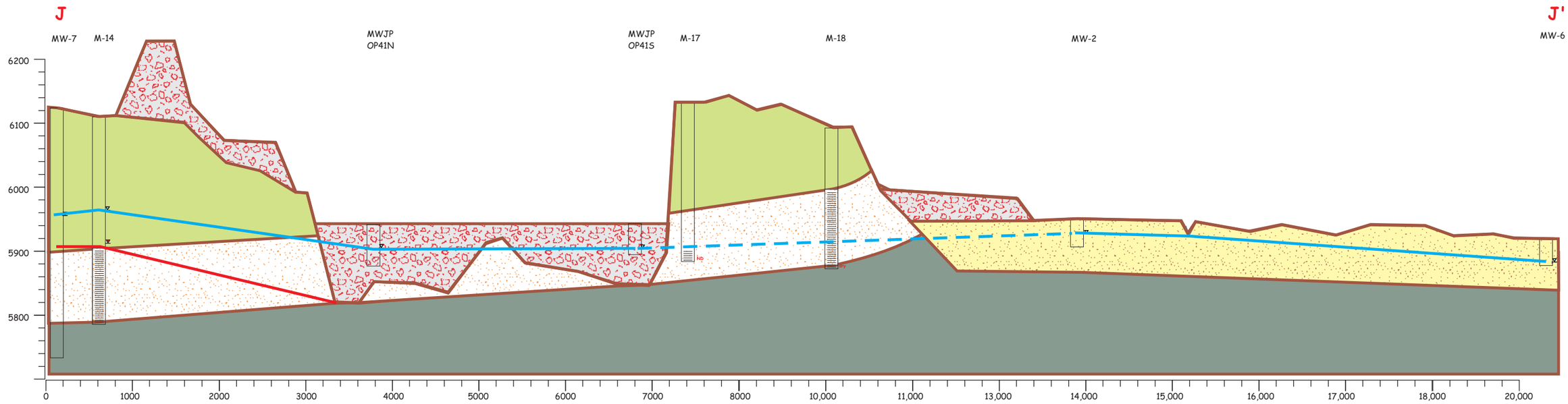
FIGURE 11
GEOLOGIC CROSS SECTIONS G-G' and H-H'
THROUGH THE JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002769







Data used to compile cross sections are from HydroSearch, 1981; USGS 1963; USGS, 1984; Anaconda, 1983, 1985, 1986, and this work.

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01

Lithology
Fill (Mine Waste)
Quaternary Alluvium
Cretaceous Formations (undifferentiated)
Jurassic Jackpile Formation
Jurassic Bushy Branch Member

Groundwater (2011)
Groundwater (1980)
Fault (USGS, 1963)
Diabase Dike (USGS, 1963)

NEW MEXICO

USEPA REGION 6
START - 3

FIGURE 12
GEOLOGIC CROSS SECTIONS I-I' and J-J'
THROUGH THE JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002770

350002770

Cross sections C-C' through J-J' can be used to assess current groundwater-surface water interactions. The following cross sections intersect Rio Paguate, from up-gradient to down-gradient: E-E', G-G', H-H', I,-I', D-D', and J-J' cross Rio Paguate as it flows south. Cross sections H-H', F-F', and E-E' intersect Rio Moquino as it flows south to meet Rio Paguate.

Cross section E-E' intersects the Rio Paguate at the URP sampling location. At this point, Rio Paguate is at a higher elevation than groundwater in the closest well, M-8; it's not clear whether surface water can flow to the screened interval at M-8 (Jackpile Sandstone), as there is likely an aquitard that is up to 50 feet thick above the Jackpile. Surface water at this point likely loses water to the sandy units of the Mancos Shale (Cretaceous).

Cross section G-G' crosses Rio Paguate near three wells: 8D, MW-4 and M-23. Rio Paguate appears to be gaining water at this location, according to the higher groundwater levels in 8D and MW-4. Interpretation of the 1980 data, however, suggests that depressed groundwater in the vicinity of the North Paguate Pit means that Rio Paguate was likely losing water to the backfill of the pit. The implication is that the North Paguate Pit was likely replenished in part from the surface water reservoir as much, if not more than, the Jackpile Sandstone reservoir.

Cross section H-H' intersects Rio Paguate to the southeast of the North Paguate Pit. Groundwater elevations in the adjacent wells are higher than the surface water, suggesting that Rio Paguate is gaining water through this interval.

Cross section H-H' also intersects Rio Moquino where it flows into the site along the northern boundary. At this location, Rio Moquino is approximately 20 feet below the groundwater elevation measured in MW-RM, which is screened either in the Alluvial Aquifer or a sand unit of the Mancos. Assuming that groundwater and surface water are connected, then Rio Moquino should be gaining water at this location.

Cross section F-F' intersects Rio Moquino in an area at least 3000 feet from the nearest well. Therefore, no implications for groundwater loss or gain can be made. The river at this point is mantled by waste piles from the mine, and flows through alluvium that is likely derived in part (or completely replaced with) waste rock and/or tailings. It is also not clear whether the alluvium is in contact with the Jackpile Sandstone or Dakota Formation in this section.

Cross section E-E' intersects Rio Moquino just above the confluence with Rio Paguate. Based on groundwater elevations from M-4 and M-16, Rio Moquino appears to be gaining water through this area. Groundwater appears to flow from both the North Paguate Pit to the west, as well as the Jackpile Pit to the east. This groundwater, as well as any meteoric water falling in this area, flows through layers of waste rock, tailings, alluvium, and remnant Jackpile Sandstone.

Cross section I-I' crosses Rio Paguate just below its confluence with Rio Moquino. Groundwater elevations to the north are higher than Rio Paguate. To the south, M-26 has groundwater elevations slightly higher than Rio Paguate. It is unclear from the cross section whether groundwater in the Jackpile to the north communicates with the alluvial groundwater

around Rio Paguate; the Jackpile is exposed above the river level in this area. M-13 was dry in 1980 through 1982; the field team were unable to acess this well during the 2011 ESI.

Cross section J-J' intersects Rio Paguate just inside the southern site boundary, near the RP-02 sampling point. Wells MW-2 and MW-6 are screened in the Alluvial Aquifer, which rests against Bushy Basin bedrock through this area. The wells are far enough from the intersection of the river to make it difficult to determine from the cross section whether the river is gaining or losing water; however, the surface water sampling team reported that Rio Paguate was dry at this location during the 2011 ESI event. It is therefore probably reasonable to state that Rio Paguate loses water through this interval, at least in the waning stages of the high-flow season.

2.6 Aquifer/Aquifer Interactions

Well testing conducted by the USGS in 1984 provides hydrologic conductivities (K) of the Alluvial and Jackpile aquifers (USGS 1984). Groundwater from the Jackpile is capable of flowing into the alluvium and back, depending on the relative hydraulic head of each reservoir. From a hydrologic standpoint, groundwater is only likely to flow from the Jackpile to the Alluvial Aquifer (Qal) under conditions where the Jackpile Aquifer (Jmj) is either physically above the Alluvial Aquifer, or otherwise has a higher hydraulic head. This is because the hydraulic conductivity of the Jackpile is two orders of magnitude lower than that of the Alluvial Aquifer (K_{Jmj} = 0.3 feet/day vs. K_{Qal} = 23 feet/day); where in hydrostatic equilibrium, chemical communication between these water bodies would primarily be by diffusion. This occurs in a few locations near the confluence of Rios Paguate and Moquino (see cross sections in Figures 7 through 10).

That same 1984 USGS study demonstrated that the Alluvial and Jackpile aquifers are in hydraulic communication where they are in contact, based on pump tests performed at the M-4 cluster. Pumping on well M-4C, which is screened entirely in the Alluvial Aquifer, had a measurable drawdown effect on M-4 and M-4A, which are screened in the Jackpile Aquifer. Water chemistry in MW-4, as described in detail in Section 3 below, is more consistent with the surface and alluvial water than the Jackpile water.

Based on these studies, as well as the interpreted groundwater elevation data presented in the cross sections in Figures 7 through 10, it is possible for groundwater to flow from the Jackpile Sandstone to the Alluvial Aquifer under limited conditions. The rate of flow is limited by the conductivity of the Jackpile Sandstone and the relative hydraulic head between the two reservoirs. It is also possible for waters from other sources (Alluvial Aquifer, surface water, pit water) to flow into the Jackpile Sandstone, and use it as a conduit for migration.

2.7 Hydrologic Conclusions

The hydrologic system of the Jackpile-Paguate Mine Site includes surface water, and groundwaters of the Jackpile Sandstone, Alluvial Aquifer, and waters of the backfilled Paguate and Jackpile pits. Hydrologic studies indicate that these reservoirs interact with each other in a fairly complicated manner based on surface water flow rates and the hydraulic conductivities of the reservoirs where they are in contact with one another.

Mining activities have historically lowered groundwater elevations in the upgradient areas of the site, but not the downgradient areas. The cessation of mining activities, as well as the backfilling of the Paguate and Jackpile pits, has caused the groundwater system to rebound. This rebound was predicted before the pits were backfilled; however, the rate of groundwater rebound appears to be faster for the South Paguate Pit than anticipated. The models predict that groundwater accumulating in the pits will flow through the natural (Jackpile and Alluvium) geologic materials, as well as waste rock and tailings, to flow into the surface water system (Dames and Moore, 1983).

Geologic cross sections completed through the site indicate that surface water may have flowed into the North and South Paguate pits, causing groundwater to rebound more quickly than modeled. Groundwater elevations indicate that groundwater from the North Paguate and Jackpile pits is flowing into Rio Moquino. Groundwater from the South Paguate Pit appears to be flowing into Rio Paguate, and water from Rio Paguate (and/or the associated Alluvial Aquifer) may be flowing into the North Paguate Pit (see Cross Section G-G', Figure 9).

3.0 Aqueous Geochemistry

This section examines the water chemistry of the three natural hydrologic reservoirs in the system: surface water, the Alluvial Aquifer, and the Jackpile Sandstone. These reservoirs co-mingle in the area of the mine site, where excavation, tunneling, and mounded water in waste-rock piles provide a place for these waters to temporarily pool and react with these anthropogenically-altered materials.

The three detailed investigations into the groundwater chemistry at the site include two pre-remedial studies (Hydro-Search, 1979; 1981), and the post-remedial ROD study (OA Systems, 2007). All of these studies identified two distinct water chemistries across the site; however, the ROD study lacks critical hydrologic data (e.g. water levels, stream gauging data, etc.). Chemical data from the ROD vary considerably from year to year, and Quality Assurance/Quality Control issues brought up in the ROD Assessment call many of these data into question.

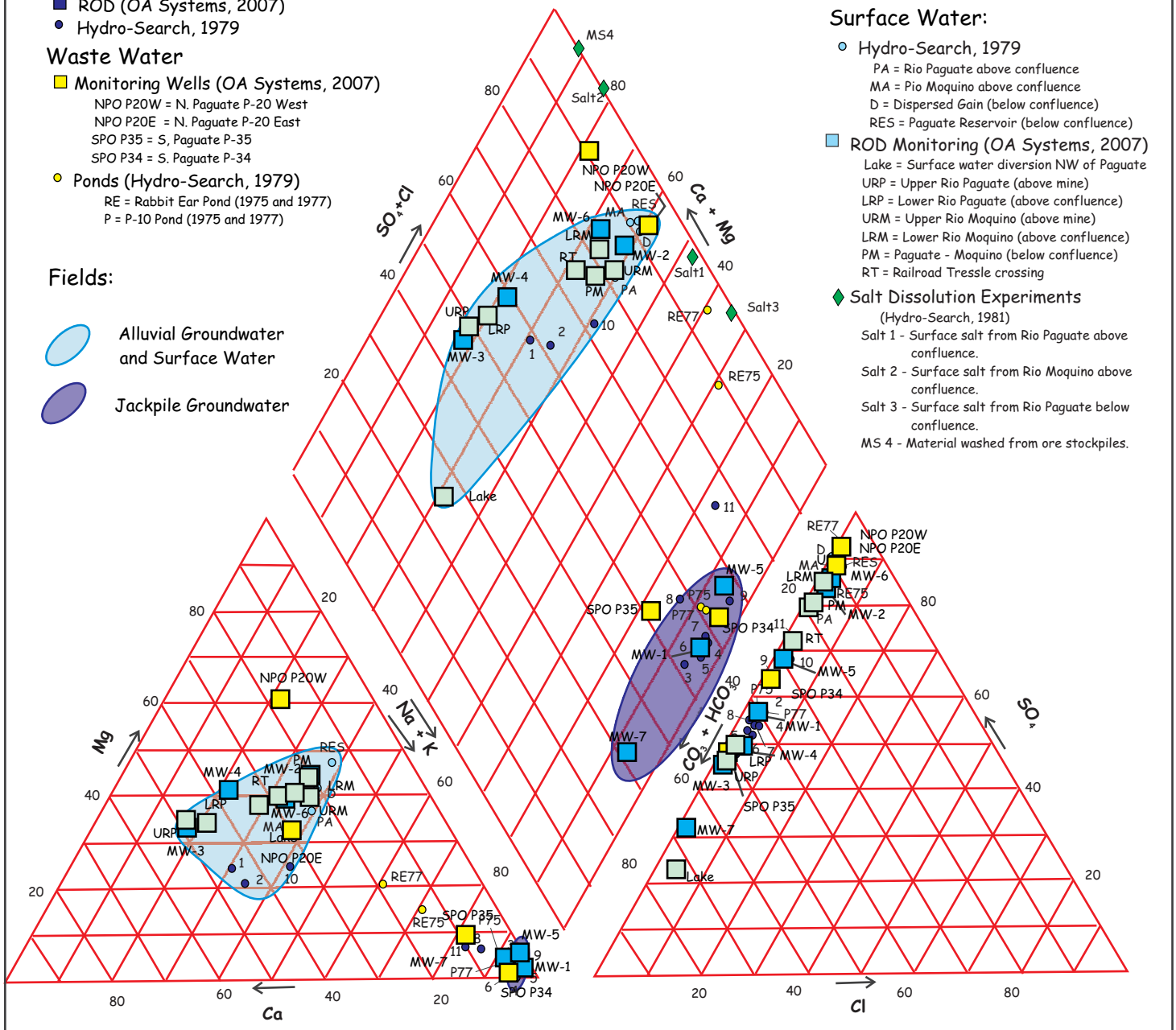
3.1 Historical Cation/Anion Data

General cation/anion data from the historical studies are reproduced in Figure 13. As stated above, surface waters and groundwater from the Alluvial Aquifer fall into a Ca+Mg sulfate-bicarbonate classification. Groundwater from the Jackpile Aquifer falls into a Na+K sulfate-carbonate-bicarbonate category (Hydro-Search, 1979; 1981). In spite of minor variations between the Hydro-Search (1979) and OA Systems (2007) data sets, there is good delineation of two groundwater populations distinguishing waters of the Jackpile Sandstone and the Alluvial/Surface water system.

Also included in Figure 13 are water chemistry data from two holding ponds at the site that existed in the late 1970s. Water in the P-10 holding pond was pumped from the underground workings located on the southwestern wall of the South Paguate Pit; this water plots with the Jackpile water chemistry, as expected. Water in the "Rabbit Ear Pond was pumped from the Jackpile Pit during mining activities; this water plots in the sulfate range, between the down-gradient Alluvial/Surface water and Jackpile water.

The Alluvial/Surface water chemistry of Rio Paguate tends to increase from a sulfate-bicarbonate chemistry to predominantly sulfate chemistry as it moves through the site. This may be in part due to the higher sulfate chemistry, as well as the higher TDS of the Rio Moquino water as the two reservoirs meet. The analysis of cation/anion chemistry below also suggests that this trend may be due to the interactions of surface and ground water with mineral materials, including natural alluvium, efflorescence, mine tailings, protore, and waste rock that occur through this reach.

In 1981, Hydro-Search performed leachate tests on various materials from the site, including protore and efflorescence samples collected from the dry portions of the river bottoms, to determine the effects of groundwater interaction with site materials. The study used water collected from the P-10 workings as the leaching solvent. The leachate waters were analyzed for



USEPA REGION 6 **START - 3** CERCLIS ID: NMN000607033 SSID: A6T3 TDD: TO-0019-10-11-01	DATE July 2011 PROJECT NO. 20406.012.019.0603.01	FIGURE 13 Historical Surface and Groundwater Chemistry JACKPILE-PAGUATE URANIUM MINE SR 279 Laguna Pueblo Paguate, Cibola County, New Mexico	**Figure** 13

350002775

cation/anion chemistry, as well as metals and radiological contaminants. What is interesting is that the protore leachate is much more similar to the salt leachates than the Jackpile groundwater (Hydro-Search, 1981).

The ROD data (OA Systems, 2007) include surface water data, as well as groundwater data from the post-remedial wells. The surface water sampling points stretch out from the lake above the town of Paguate, through the mine site, and farther south toward the Paguate Reservoir. Most of the groundwater wells installed along the site (MWs 2, 3, 4, and 6) overlap the downgradient portion of the surface water field very well. The two fields form a narrow trend extending toward the sulfate end of the anion spectrum. MWs 1 and 7 plot in the sodium bicarbonate-sulfate field, and are typical of the Jackpile Aquifer.

The ROD also includes data from wells installed in the backfill of the North and South Paguate pits. The North Paguate Pit waters plot in the vicinity of the salt leachate experiments from 1981 (Hydro-Search, 1981), as well as the Rabbit Ear Pond water from the 1979 study (Hydro-Search, 1979). The South Paguate Pit waters plot in the field of the Jackpile Sandstone. The implication here is that the South Paguate Pit is filling primarily with water from the Jackpile, and may not have been vigorously reacting with the backfill materials. The North Paguate Pit, on the other hand, may have been either receiving water from the Surface/Alluvial reservoir, and/or reacting substantially with the backfill material to produce a calcium+magnesium-sulfate groundwater chemistry.

3.2 ESI Water Chemistry Data

Water chemistry data were generated for groundwater and surface water samples collected during the 2011 ESI event. Field data, including temperature, specific conductivity, pH, dissolved oxygen, and oxidation/reduction potential (ORP) were recorded at the time of sampling. Water samples were submitted to an EPA-approved laboratory for analysis for cations, anions, TDS, alkalinity, metals, gross alpha, gross beta, isotopic radium, and isotopic uranium. Water quality results (cations, anions, TDS and alkalinity), along with field measurements, are presented in Table 3.

The cation/anion data for the 2011 groundwater and surface water sample suites are presented in Figures 14 and 15, respectively. Most of the surface water data plot generally with the 1979 and 2007 ROD surface water data; however, the downgradient locations are more spread out along the high-sulfate side of the diagram. The results for MWs 2, 3, and 6 plot in approximately the same areas as in the 2007 data set; MW-RM also predictably plots with this population. MW-MD plots very close to surface water sample, MD, in the most sulfate- and sodium-dominated chemistry of the Alluvial/Surface Water system. The water chemistry of MW-4 appears to have shifted significantly toward the sulfate end of the spectrum in the 2011 data set.

MWs 1, 7 and 8 plot in the sodium+potassium, bicarbonate-sulfate field that is consistent with the Jackpile Aquifer. The water chemistry of MW-1 has shifted significantly toward the calcium + magnesium + sulfate end of the spectrum; this suggests that groundwater at this location may be influenced by alluvial or pit waters.

Table 3: Water Quality Analyses and Field Measurements

		Laboratory Results										Field Measurements				
		Cations				Anions				TDS	Alky					
		Ca	Mg	Na	K	CO3	HCO3	Cl	SO4			Temp	pH	Sp Cond	Diss O_2	ORP
Groundwater	Description	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l		°C		NTUs	mg/l	mv
MW-1	Background	24.5	85.54	867	7.031	(<20)	465	15.6	1190	2000	470	16.76	7.78	2597	3.72	133.6
MW-2	On-Site	247	279	648	18.7	(<20)	473	39.7	2460	3500	475	18.47	7.42	1194	12.8	100.8
MW-3	On-Site	192	641	810	5.92	(<20)	311	7.9	381	785	312	11.96	6.95	1299	10.03	101.7
MW-4	On-Site	203	121	152	11.8	(<20)	450	14.9	1560	1210	451	13.37	7.1	1782	8.12	62.7
MW-6	Downgradient	278	205	450	16.9	(<20)	369	32.9	1650	2690	370	15.36	7.18	3056	9.81	-23.5
MW-7	Background	3.4	1.64	289	1.82	(<20)	334	3.5	106	515	351	17.73	8.65	819	2.94	71
MW-8	Background	13.2	1.59	593	5.59	(<20)	445	19.4	350	940	452	17.94	8.01	1656	5.64	103
MW-MD	Downgradient	200	237	1310	12.6	(<20)	577	128	3790	7250	580	20	7.74	6960	12.15	115.8
MW-RM	Background	146	111	187	19.4	(<20)	218	14	454	1340	220	14.81	7.6	1896	10.84	111
NPOP20E	Source	571	276	1260	39.7	(<20)	590	18.9	3580	4440	590	14.83	6.29	5289	7.7	45.4
SPOP35	Source	483	359	2030	63.5	(<20)	619	41.7	5500	9360	620	19.6	6.91	9640	7.73	112.5
JPOP41S	Source	744	581	561	52	(<20)	999	15.4	3140	6370	1000	18.01	7.43	5067	12.05	117.3
Surface Water																
PR-SW-01		1010	471	1200	92.8	(<20)	75	145	5330	7950	80	18.04	7.84	6179	11.13	90
RM-JM-SW	R. Moquino above confluence	218	217	519	18.1	(<20)	287	24.5	1920	2410	291	20.55	8.17	2948	9.53	131
RM-SW-BG	R. Moquino Bkgd	117	106	280	15.0	(<20)	246	13.4	877	1260	250	20.6	9.34	1686	7.8	-149.8
RP-JM-SW-01	R. Paguate below confluence	200	150	295	15.3	(<20)	281	19.1	1040	1800	284	20.49	8.11	2154	7.96	129.7
RP-JM-SW	R. Paguate above confluence	181	97	127	12.3	(<20)	282	13.0	642	1220	285	1789	8.09	1336	7.81	128.6
RP-SW-01	R. Paguate site south site boundary	223	211	445	17.3	(<20)	329	27.2	1640	2120	333	20.52	9.99	2733	-	115.7
RP-SW-BG	R. Paguate Bkgd	124	36	73	6.2	(<20)	339	6.4	146	420	343	12.06	9.61	818	-	115.1
MD-SW	Mesita Dam	270	198	1290	26.8	(<20)	317	363.0	2050	3860	322	21.29	8	4562	10.05	133.3
RP-SW-02	R. Paguate below site	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RP-SW-03	R. Paguate below site	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Green rows indicate background locations

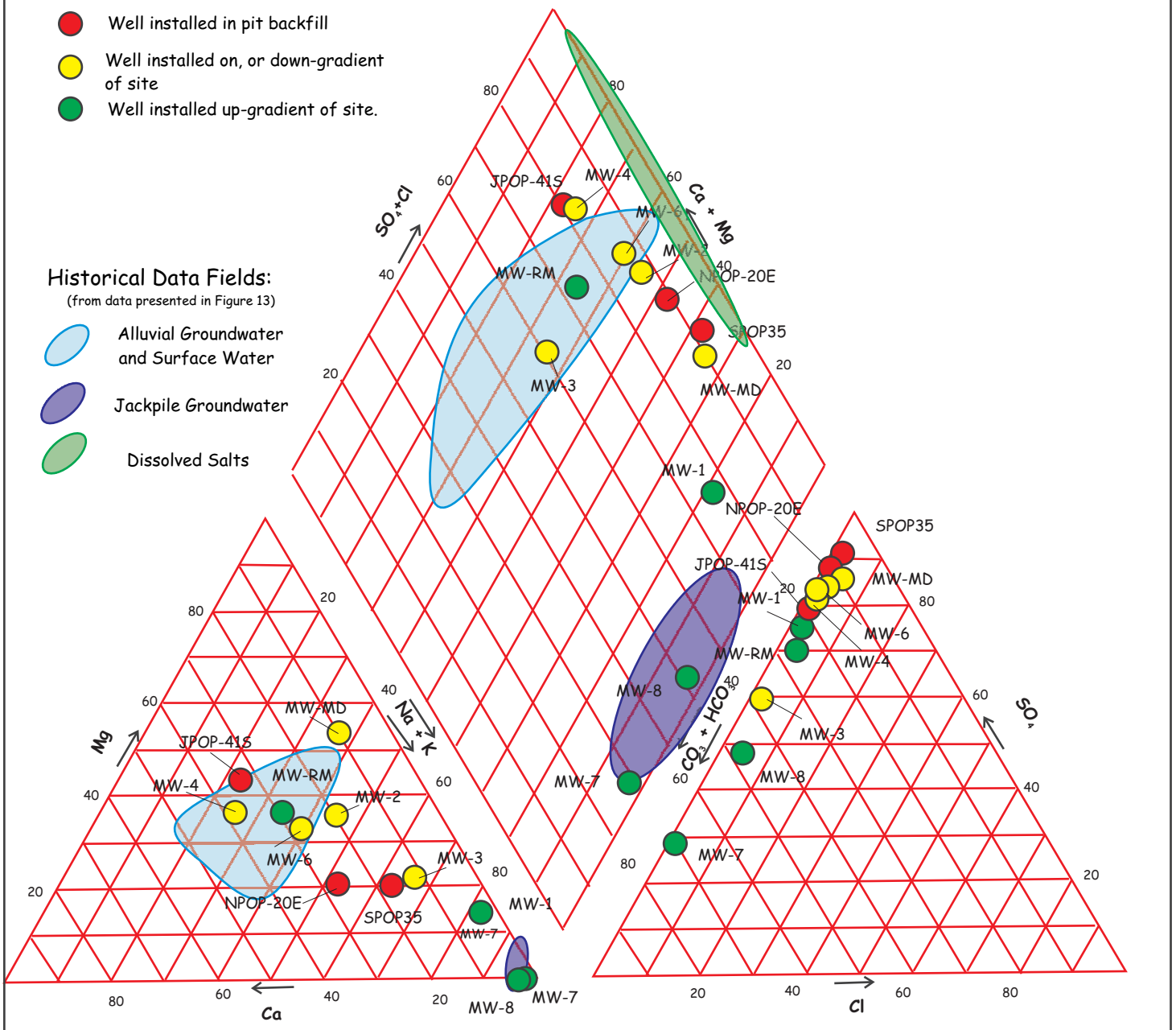
Alky = alkalinity

mg/l = milligrams per liter

mV = millivolts

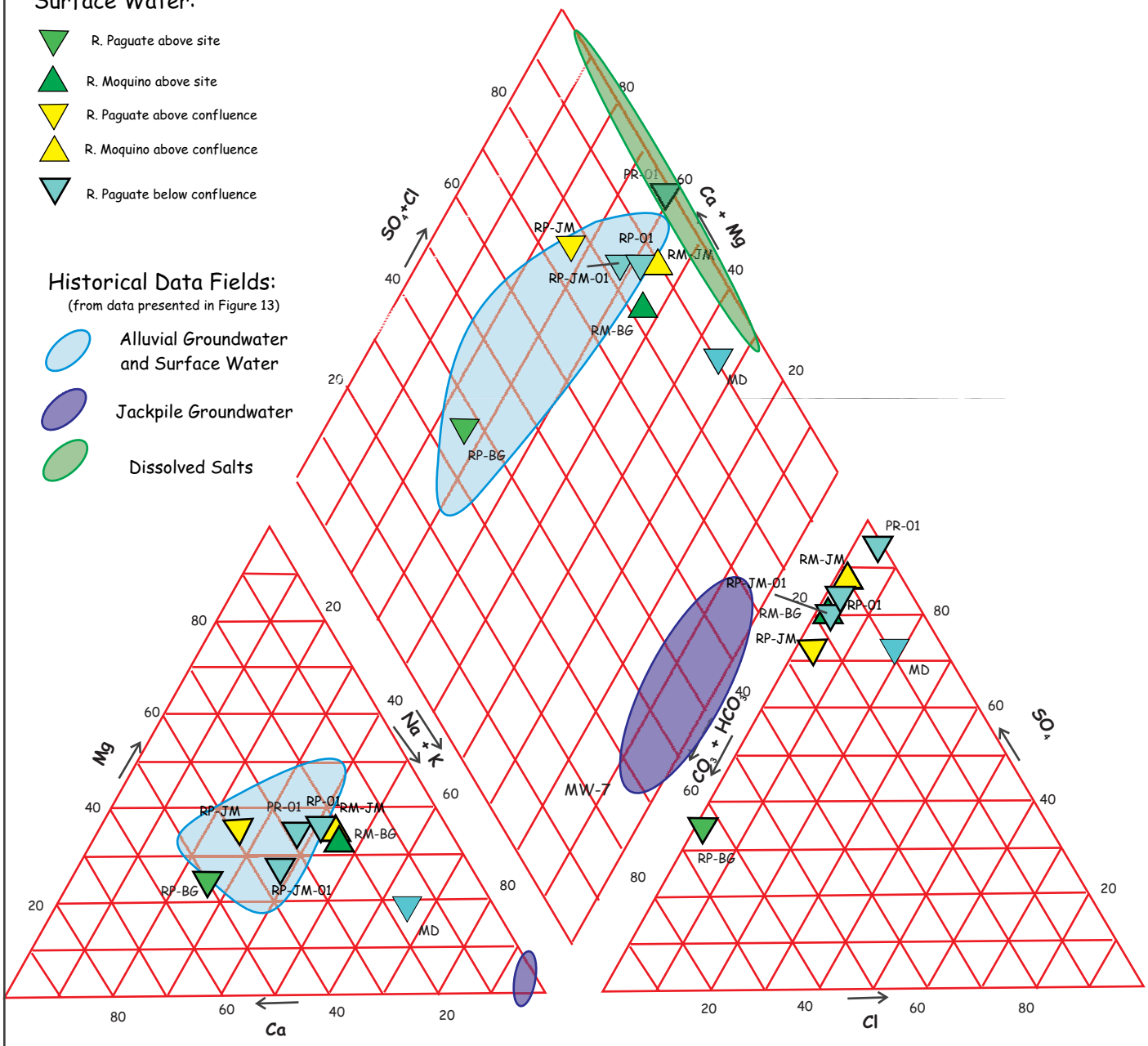
NTU = Nephelometric Turbidity Units

350002777



USEPA REGION 6 **START - 3** CERCLIS ID: NMN000607033 SSID: A6T3 TDD: TO-0019-10-11-01	DATE July 2011 PROJECT NO. 20406.012.019.0603.01	FIGURE 14 2011 ESI Groundwater Chemistry JACKPILE-PAGUATE URANIUM MINE SR 279 Laguna Pueblo Paguate, Cibola County, New Mexico	**Figure** **14**

350002778



USEPA REGION 6 **START - 3** CERCLIS ID: NMN000607033 SSID: A6T3 TDD: TO-0019-10-11-01	DATE July 2011 PROJECT NO. 20406.012.019.0603.01	FIGURE 15 2011 ESI Groundwater Chemistry JACKPILE-PAGUATE URANIUM MINE SR 279 Laguna Pueblo Paguate, Cibola County, New Mexico	**Figure** 15

350002779

The 2011 ESI data also include water samples from three of the wells installed in the backfilled pits: one each from the North Paguate, South Paguate, and Jackpile pits. In general, the pit waters plot along the same fanning trend observed at the sulfate end of the Alluvial/Surface Water data array. The Jackpile pit water sample plots at the far, magnesium + calcium range of this fanning trend, and the Paguate pit waters plot approximately where the Rabbit Ear Pond water plot. What is most surprising about the 2011 data is that SP-OP-35 (South Paguate Open Pit No 35) now plots with the Alluvial/Surface Water trend, where it plotted with the Jackpile trend in the 2007 data set.

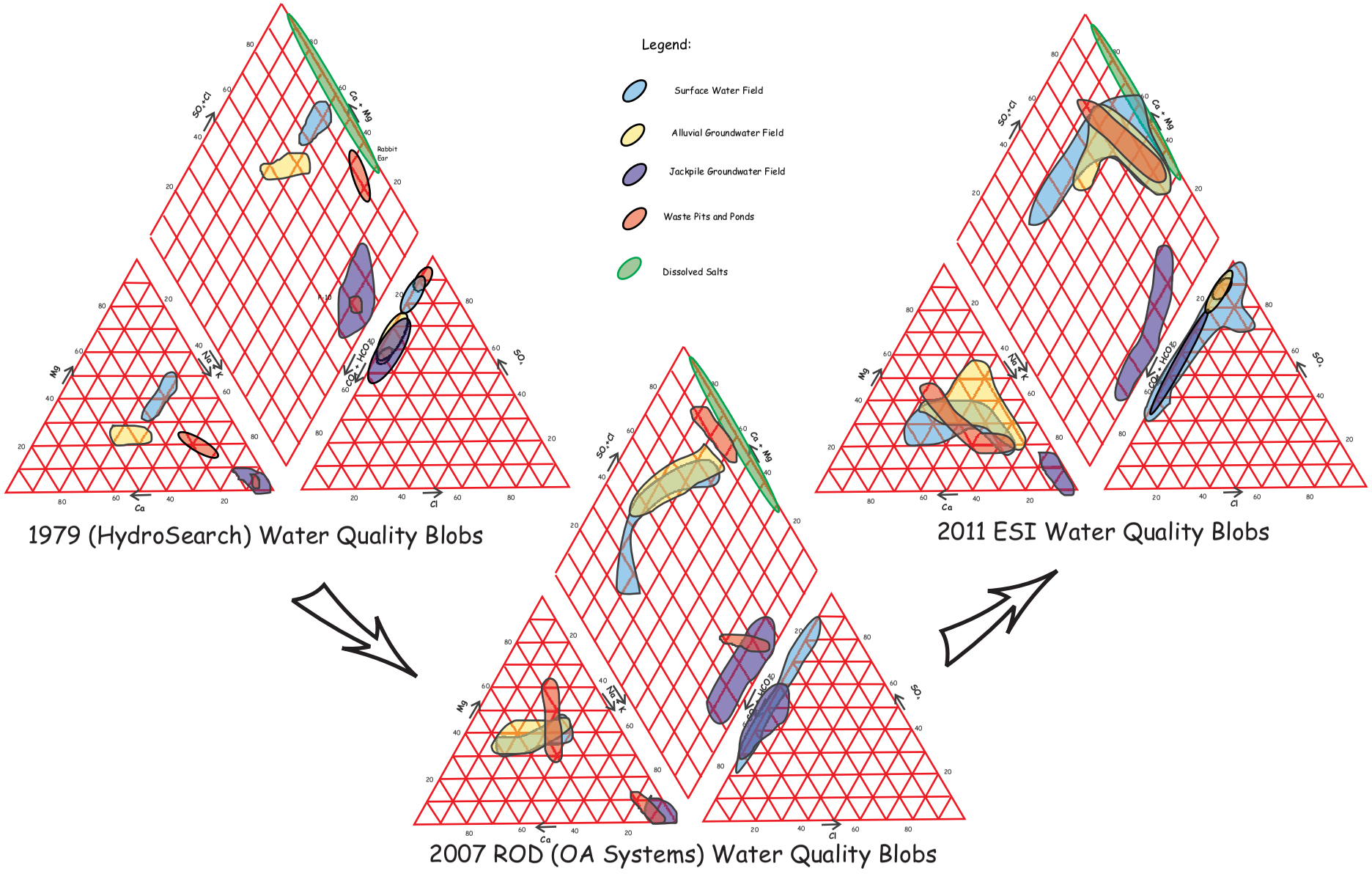
The salt and protore leachate sample results lie along the far sulfate end of the Piper diagrams, spread out over a range of calcium + magnesium to sodium + potassium cation chemistries. It appears that the evolutionary trend for water chemistries in both the Jackpile Aquifer and Alluvial/Surface Water systems is toward this composition. It is highly likely that water reactions with mineral materials, including natural alluvium, efflorescence, waste rock, tailings and protore materials in the backfill and waste piles, are responsible for this shift in chemistry as the water system progresses down-gradient.

Figure 16 shows the 1979, 1981, 2007 ROD, and 2011 ESI anion/cation data plotted as three separate time slices. Noting the lack of complete coverage in the 1979 data (as well as the differences in quality assurance issues with the various data sets), there appears to be a temporal trend of the surface- and groundwater system toward the "leachate" end-member. The most substantial change in water chemistry is observed in the South Paguate Pit, and the pit water chemistry is close to the theoretical, "leachate" endmember (as well as pond waters extracted from the historical workings). While not definitive, the data suggest that the groundwater and surface water chemistry under, and down-gradient of, the site is shifting toward a highly sulfate chemistry, and the cause of this may be chemical reactions taking place between groundwater rebounding into the backfilled pits and mine wastes encountered by the rebounding groundwater.

The finding is preliminary, as it is based on three slices through the data set. It will likely take multiple quarters of sampling to determine whether this apparent trend is actually a long-term geochemical trend, a seasonal variation, or an anomaly in the data. If this is actually happening, however, then there could be significant, long-term consequences for the lower Rio Paguate.

3.3 Uranium in Surface and Ground Water

The historical uranium data show that uranium concentrations increase in both surface water and groundwater across the site. This is apparent in multiple data sets collected from 1979 to the present (Hydro-Search, 1979, Anaconda, 1983; 1985; 1986; OA Systems, 2007; Weston 2010, this report). Table 4 shows a summary of historical uranium data collected at the site from surface water and groundwater locations from the period 1979 to the present. In every case, on-site and down-gradient sampling locations have uranium concentrations that are higher than background, and significantly greater (greater two standard deviations above the mean of background) in most cases for both surface water and groundwater.



Data used to compile fields in this Piper Diagram are from HydroSearch, 1979, HydroSearch, 1981; OA Systems, 2007, and this work.

CERCLIS ID: NMN000607033
SSID: A6T3
TDD: TO-0019-10-11-01

USEPA REGION 6
START - 3

DATE
July 2011

PROJECT NO.
20406.012.019.0603.01

FIGURE 16
Water Quality Blobs for Historical and 2011 Data
THROUGH THE JACKPILE-PAGUATE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

Table 4 Historical Uranium Data

Hydro-Search, 1979			Anaconda, 1983; 1985; 1986									OA Systems, 2007		circa 1995 - 2007	
		1979			Oct-80	Apr-81	Apr-82	Apr-83	Jul-84	Apr-85	Jul-86			low	high
Groundwater		mg/l	Groundwater		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Groundwatater		mg/l	mg/l
Well #1		**0.053**	M-2 (S. Paguate Pit)		-	-	-	-	**0.009**	0.001	0.002	MW-01	BKGD	0.01	6.27
Well #2		**0.16**	M-4 (confluence)		-	-	-	-	0.003	0.003	0.001	MW-07	BKGD	0.002	12
Well #3	BKGD	0.009	M-6 (upgradient of S. Paguate Pit)	BKGD	-	-	-	-	0.002	0.001	0.001	SPOP35	Backfill	5.12	56523
Well #4		**0.87**	M-10 (S. Paguate Pit)		-	-	-	-	**0.066**	**0.067**	**0.054**	SPOP34	Backfill	0.08	106.7
Well #5		**0.012**	M-14 (upgradient of Jackpile Pit)	BKGD	-	-	-	-	0.001	<0.001	0.001	NPOP20W	Backfill	0.77	1258
Well #6		**0.038**	M-16 (Jackpile Pit)		-	-	-	-	**0.032**	**0.045**	**0.044**	NPOP20E	Backfill	27.7	104501
Well #7	BKGD	<0.006	"B" (S. Paguate Pit)		-	-	-	-	**0.008**	0.003	**0.007**	MW-02	on site	0.07	299
Well #8		**0.043**	"C" (east of N. Paguate Pit)		-	-	-	-	**1.950**	**1.486**	**1.352**	MW-03	on site	0.04	419
Well #9	BKGD	0.007	"D" (Jackpile Pit)		-	-	-	-	**0.400**	**0.634**	**0.128**	MW-04	on site	0.11	624
Well #10		**0.25**	Jackpile Well # 4		0.013	0.015	0.006	0.003	-	-	-	MW-05	Bushy Bsn	0.0002	9.35
Well #11		**0.062**	Jackpile New Shop Well		0.018	0.011	0.006	0.005	-	-	-	MW-06	Alluvium	0.07	45.9
Surface Water			Jackpile Old Shop Well		0.082	0.145	0.33	0.32	-	-	-				
RPW (R. Paguate upstream)	BKGD	0.006	Surface water												
RMW (R. Moquino upstream)	BKGD	0.006	R. Paguate upstream	BKGD	0.002	0.011	0.005	0.0034	0.003	0.001	0.0031				
RPC (R. Paguate midway above confluence)		**0.02**	R. Moquino upstream	BKGD	0.001	0.01	0.011	0.0044	0.012	0.003	0.0085				
PA (R. Paguate above confluence)		**0.58**	R. Paguate above confluence		**0.082**	**0.032**	0.011	**0.023**	**0.17**	**0.022**	**0.0392**				
MA (R. Moquino above confluence)		**0.15**	R. Moquino above confluence		**0.077**	**0.027**	**0.027**	0.0095	**0.406**	0.009	**0.0505**				
RPB (railroad bridge)		**0.39**	Rio Paguate @ ford		**0.26**	**0.053**	**0.049**	**0.019**	**0.251**	**0.048**	**0.1428**				
			Paguate Reservoir		**0.267**	**1.214**	**0.21**	**0.052**	**0.136**	**0.042**	**0.0389**				

Green rows indicate background locations.

Results in **red** indicate significantly elevated with respect to background (greater than 2xstandard deviation above the mean of the background population).

Uranium results are reported in milligrams per liter (mg/L); although some of the ROD data (OA Systems) may have been reported in the wrong units, and are likely analyzed as "picoCuries per liter" (pCi/L).

350002782

It's curious to note how many different groundwater well sets have been used at various times, especially during the period 1979 through 1986. START-3 could find no reports describing the installation or abandonment of these wells, nor any information about what decisions lead to the installation of new wells.

Radiological results from the 2011 ESI are presented in Table 5 below. Results from the ESI are also presented spatially in Figure 17. Analyses include isotopic uranium, thorium, radium, gross alpha, and gross beta.

In the groundwater samples, radionuclides are significantly above background in many of the on-site and downgradient wells. The background wells include MW-RM, MW-1, MW-7, and MW-8. Total uranium (the sum of the activities of the isotopic species) activity in the background wells ranges from 4.3 to 42.4 pico-Curies per liter (pCi/L), and 33.8 to 231.7 pCi/L in the on-site and down-gradient wells. Total uranium activities in the pit wells ranges from 24,240 to 249,515 pCi/L. Gross alpha and beta, and isotopic radium activities are also significantly elevated in the pit waters with respect to background.

In the surface water samples, radionuclides are significantly above background in water samples collected at all of the on-site and downgradient locations, except from the Mesita Diversion. The background locations include RP- BG and RM- BG, which were collected in Rios Paguate and Moquino, respectively, above the site boundary. Total uranium (the sum of the activities of the isotopic species) activity in the background locations are reported at 10.2 to 6.4 pCi/L. Total uranium activites in the on-site and downgradient surface water samples range from 32.6 to 167.1 pCi/L in the five down-gradient samples that are significantly above background. The sample collected at the Mesita Diversion has a total uranium activity of 7.9 pCi/L.

3.4 Uranium in Surface Water Sediments

Sediment samples were collected at each of the surface water sampling locations during the 2011 ESI event. Uranium was not detected at significantly high concentrations in sediments collected during the 2010 SI event. For the 2011 ESI, START-3 collected efflorescent sediment samples (as opposed to clastic sediments) because it was considered that uranium oxide species might be transported almost entirely as dissolved load in the surface water and groundwater system.

Uranium exists as a complex, organo-oxide cement in the +4 valence state in the Jackpile Sandstone (Owen, et al., 1983). Uranium oxides in the +4 valence state are generally insoluble and remain in solid form. Uranium deposition occurs when uranium-bearing fluids encounter, and react with, organic material in the formation; the reducing environment causes the conversion from a +6 to a +4 valence state, and precipitates uranium oxide minerals. The weathering environment is oxidizing and promotes the conversion from a +4 to a +6 valence state, which is soluble (Park and MacDiramid, 1975). Erosion of the Jackpile Sandstone yields resistant sand grains (mostly quartz and potassium feldspar) while the cement, including the uranium oxide mineralization, is dissolved.

Table 5: 2011 Radionuclide Data

	Designation	Th^{228}	Th^{230}	Th^{232}	Thtot	U^{234}	U^{235}	U^{238}	Utot	Gross α	Gross β	Ra^{226}	Ra^{228}
Groundwater		pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l
MW-1	Background	0.0440	0.1222	0.0072	0.1733	3.7433	0.1607	0.8257	4.730	13.4	<3.58	<0.74	1.26
MW-2	On-Site	0.0128	0.0042	<0.0044	0.0214	**63.555**	**2.2324**	**54.37**	**120.16**	65.5	99.3	<0.74	<0.92
MW-3	On-Site	0.0080	0.6453	0.0312	0.6844	**17.713**	0.6496	15.44	33.80	43	5.3	<0.74	<0.92
MW-4	On-Site	<0.013	0.1286	0.0080	0.1366	**118.950**	**4.5793**	**108.23**	**231.76**	142	91.3	<0.74	<0.92
MW-6	Downgradient	0.0264	0.6735	0.0406	0.7405	**73.205**	**2.6290**	**61.80**	**137.63**	61.8	66.7	<0.74	2.51
MW-7	Background	0.0356	0.4854	0.0388	0.5598	3.8034	0.0615	0.4432	4.308	1047	<3.58	2.71	1.11
MW-8	Background	0.0040	0.9379	0.0118	0.9537	5.2096	0.0585	1.9547	7.223	40.5	224	<0.74	<0.92
MW-MD	Downgradient	0.0092	0.8585	0.0087	0.8765	**31.29**	**1.0008**	22.77	**55.06**	27	17.8	1.34	<0.92
MW-RM	Background	0.0123	1.0345	0.1045	1.1513	11.65	0.73272	30.02	42.40	<2.28	11.22	<0.74	<0.92
NPOP20E	Source	0.0374	**1.8536**	0.1099	2.0009	**36513**	**40367**	**64338**	**141219**	3624	**26301.04**	**33.23**	**13.93**
SPOP35	Source	0.0754	0.5921	0.0997	0.7672	**7838**	**6450**	**9952**	**24240**	1326	**2314.11**	**17.29**	**17.3**
JPOP41S	Source	0.2472	1.492	0.0866	1.8256	**63261**	**72122**	**114132**	**249515**	**15961**	**147252.2**	**208.45**	**38.3**
$BKGD_{2stdev}$	**Groundwater**	**0.0618**	**1.491**	**0.1302**	**1.5773**	**13.62**	**0.8995**	**37.29**	**51.74**	**1545**	**419**	**2.71**	**1.40**
Surface Water		pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l	pCi/l
PR-SW-01	Paguate Reservoir	0.0339	1.5726	0.0884	1.6949	**17.45**	**0.565**	**14.62**	**32.63**	**55**	**151.8**	<0.74	<0.92
RM-JM-SW	R. Moquino upper	0.0365	0.5445	0.1388	0.7199	**38.00**	**1.541**	**33.43**	**72.97**	**28.2**	**45.6**	<0.74	<0.92
RM-SW-BG	R. Moquino Bkgd	0.0711	0.7269	0.1260	0.9240	4.119	0.0996	2.2301	6.449	<2.28	5.6	<0.74	1.12
RP-JM-SW-01	R. Paguate lower	0.0261	0.7552	0.0766	0.8580	**32.40**	**1.236**	**29.26**	**62.89**	**30.8**	**25.9**	<0.74	<0.92
RP-JM-SW	R. Paguate upper	0.2260	0.7023	0.1419	1.0702	**28.48**	**1.071**	**24.25**	**53.79**	**35.1**	**23.7**	<0.74	<0.92
RP-SW-01	R. Paguate S. boundary	0.1041	1.0725	0.1099	1.2865	**85.10**	**3.236**	**78.79**	**167.12**	**75**	**28.1**	<0.74	<0.92
RP-SW-BG	R. Paguate Bkgd	0.1612	1.2022	0.0727	1.4361	6.242	0.2157	3.79273	10.250	<2.28	<3.58	<0.74	<0.92
MD-SW	Mesita Dam	0.0433	0.4185	0.0197	0.4814	4.858	0.3058	2.81139	7.975				
$BKGD_{2stdev}$	**Surface Water**	**0.2435**	**1.6367**	**0.1747**	**1.9043**	**8.1823**	**0.3218**	**5.221**	**13.73**	**2.28**	**7.49**	**0.74**	**1.30**
Sediment		pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg	pCi/kg
PR-SED-01	Paguate Reservoir	0.4616	**4.433**	0.5427	**5.437**	**2.124**	**0.0891**	**2.2472**	**4.460**	4.83	**9.6**	**3.17**	**3.4**
RM-JM-SED	R. Moquino upper	**1.266**	**6.829**	**1.268**	**9.363**	**5.781**	**0.2615**	**5.8879**	**11.931**	5.45	**9.75**	<1	<2
RM-SED-BG	R. Moquino Bkgd	0.8213	1.045	0.8212	2.687	0.3693	0.0198	0.3026	0.692	4.8	4.1	1.17	<2
RP-JM-SED-01	R. Paguate upper	0.3710	0.6787	0.4191	1.469	**0.6800**	**0.0489**	**0.6880**	**1.417**	2.8	1.99	<1	2.14
RP-JM-SED	R. Paguate S. boundary	1.0055	0.8590	0.9084	2.773	**0.7862**	0.0286	**0.6911**	**1.506**	4.6	2.4	1.77	<2
RP-SED-01	R. Paguate lower	0.5121	0.5845	0.4759	1.573	**0.7106**	0.0148	**0.6310**	**1.356**	1.5	1.13	1.75	<2
RP-SED-BG	R. Paguate Bkgd	0.4647	0.4538	0.4848	1.403	0.2426	0.0021	0.2015	0.446	1.9	1.34	1.71	<2
RP-SED-02	R. Paguate downgradient	0.795	**1.610**	0.7328	3.138	**0.9029**	0.0305	**0.9474**	**1.881**	5.44	4.8	1.93	<2
RP-SED-03	R. Paguate downgradient	1.130	**3.982**	0.9946	**6.107**	**1.3501**	0.1014	**1.6243**	**3.076**	4.5	3.4	2.73	<2
$BKGD_{2stdev}$	**Sediment**	**1.147**	**1.585**	**1.1287**	**3.861**	**0.4851**	**0.03611**	**0.39511**	**0.916**	**7.45**	**6.62**	**2.20**	**2.00**

Rows shaded green indicate background locations.

Rows shaded red indicate pit water locations.

BKGD2stdev is calculated 2xStandard Deviation from the mean of background; all radionuclide results equal to, or greater than this value are significantly above background.

Results in **red** are significantly elevated with respect to background.

pCi/l = Radionuclide activity measured in picoCuries per liter.

Utot = sum of uranium isotope activities; Thtot = sum of thorium isotope activities

pCi/kg = Radionuclide activity measured in picoCuries per kilogram.

350002784

RM-BG

RM-BG
SW = 6.4 pCi/L
SED = 0.69 pCi/kg

MW-7
4.3 pCi/L

MW-RM
42.4 pCi/L

MW-1
4.7 pCi/L

RP-BG
SW = 10.2 pCi/L
SED = 0.45 pCi/kg

Paguate

RP-BG

Rio Paguate

JP-OP-41S
249,515 pCi/L

RM-JM
SW = 73.0 pCi/L
SED = 11.9 pCi/kg

RM-JM

RP-JM

RP-JM-01

MW-3
33.8 pCi/L

NP-OP-20E
141,219 pCi/L

MW-4
231.8 pCi/L

RP-JM
SW = 53.8 pCi/L
SED = 1.5 pCi/kg

RP-JM-01
SW = 62.9 pCi/L
SED = 1.4 pCi/kg

MW-2
120.2 pCi/L

MW-8
7.2 pCi/L

SP-OP-35
24,239.9 pCi/L

RP-01

RP-01
SW = 167.1 pCi/L
SED = 1.36 pCi/kg

RP-02
SED = 1.88 pCi/kg

RP-02

MW-6
137.6 pCi/L

Jackpile Pit

North Paguate Pit

South Paguate Pit

Image © 2011 DigitalGlobe
Image NMRGIS

©2010

Jackpile-Paguate Mine Site

Expanded Site Inspection

Revised Conceptual Site Model

Legend:

- Site Outline
- Rivers
- Pits
- Pre-Remedial (M-Series) Wells
- Post-Remedial (MW-Series) Wells

MW = Post-Remedial Monitoring Well uranium activity in pCi/L

SW = Surface Water Sample uranium activity in pCi/L

SED = Surface Sediment Sample uranium activity in pCi/kg

N
W E
S

Scale In Miles
0 0.2 0.4 0.6 0.8 1.0

NEW MEXICO

Data Sources: 2011 ESI

Image Source: GoogleEarth Pro 2011

TDD: TO-0019-10-11-01

USEPA REGION 6
START - 3

FIGURE 17
2011 ESI Uranium Activity
JACKPILE URANIUM MINE
SR 279 Laguna Pueblo
Paguate, Cibola County, New Mexico

DATE	PROJECT NO.	SCALE
July 2011	20406.012.019.0603.01	AS SHOWN

350002785

Evaporation rates in the surface water environment in the area of the site are very high, and dissolved uranium oxides would be expected to precipitate along with the rest of the dissolved load during the evaporation process. The most likely sediment fraction where uranium oxides would be found, then, would be the precipitated salts, or efflorescents, in the surface water environment. In 1981, Hydro-Search collected three salt samples in the vicinity of the confluence of Rios Paguate and Moquino. The results of laboratory analysis of these salts indicate measurable concentrations of uranium, from 0.54 to 1.89 mg/kg.

In the surface sediment samples collected during the 2011 ESI event, total uranium activities in all on-site and downgradient samples are higher than the activities measured in background samples collected above the site. Total uranium activities for three samples are significantly above background. Total thorium activities for these three samples are also significantly above background.

3.5 Dissolved Oxygen and Oxydation-Reduction Potential

Field measurements for dissolved oxygen and ORP for surface water and groundwater samples are presented in Table 3. Dissolved oxygen in surface water samples ranges from 7.5 to 11.3 ppm, and 2.9 to 12.1 ppm in groundwater samples. ORP values in surface water range from -149.8 to 133.3 millivolts (mV); ORP in groundwater ranges from -23.5 to 133.6 mV.

Dissolved oxygen in the three background wells installed in the Jackpile Sandstone (MWs 1, 7, and 8) are the lowest in the study group, ranging from 2.9 to 5.6 ppm; ORP values in these wells range from 71 to 133.6 mV. Dissolved oxygen in the background well, MW-RM, is measured at 10.8 ppm, and ORP at this well is measured at 111 mV. The dissolved oxygen range measured in the on-site and down-gradient wells is between 8.1 and 12.8 ppm, and the ORP range is between -23.5 and 115.8 mV. The dissolved oxygen range measured in the pit wells is between 7.7 and 12.0 ppm, and the ORP values range between 45.4 and 117.3.

Table 6 shows the calculated oxidation-reduction conditions of the groundwater and surface water samples from the site. The calculations were performed in accordance with the *USGS Open File Report 2009-1004, An Excel® Workbook for Identifying Redox Processes in Ground Water* (USGS, 2009), and calculated following the guidance presented in the associated workbook. The calculations utilize dissolved oxygen values measured in the field, along with the laboratory results of laboratory analysis for nitrate (NO3), manganese (Mn), iron (Fe), and sulfate (SO4) for each sample.

The results for the groundwater analyses indicate mostly oxic conditions for background and on-site wells. The analysis shows mixed oxic-anoxic waters for the pit waters, as well as groundwater at MW-2 and MW-MD.

Table 6: Reduction-Oxidation Calculations based on USGS 2009.

Sample ID	O2	NO3-	Mn2+	Fe2+	SO42-	Redox Assignment	
	mg/l	mg/l	mg/l	mg/l	mg/l	General Redox Category	Redox Process
MW-1	3.72	2.4	0.00043	0.0106	1190	Oxic	O2
MW-2	12.8	0.115	0.275	1.15	2460	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
MW-3	10.03	0.115	0.00043	0.0106	381	Oxic	O2
MW-4	8.12	0.115	0.0324	0.0106	1560	Oxic	O2
MW-6	9.81	0.115	0.0193	0.0924	1650	Oxic	O2
MW-7	2.94	0.115	0.00043	0.0174	106	Oxic	O2
MW-8	5.64	0.115	0.00043	0.0239	350	Oxic	O2
MW-MD	12.15	0.115	0.654	1.45	3790	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
MW-RM	10.84	0.115	0.00043	0.0106	454	Oxic	O2
NPOP20E	7.7	0.115	4.633	3.18	3580	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
SPOP35	7.73	0.115	0.186	0.0504	5500	Mixed(oxic-anoxic)	O2-Mn(IV)
JPOP41S	12.05	54.4	2.84	0.0106	3140	Mixed(oxic-anoxic)	O2-Mn(IV)
MD-SW	10.05	0.115	0.151	0.0106	2050	Mixed(oxic-anoxic)	O2-Mn(IV)
PR-SW-01	11.13	0.115	0.97	0.269	5330	Mixed(oxic-anoxic)	O2-Fe(III)/SO4
RM-JM-SW	9.53	0.115	0.0131	0.0106	1920	Oxic	O2
RM-SW-BG	7.8	0.115	0.00043	0.0106	877	Oxic	O2
RP-JM-SW-01	7.96	0.115	0.0348	0.0106	1040	Oxic	O2
RP-JM-SW	7.81	0.115	0.0374	0.0106	642	Oxic	O2
RP-SW-01	7	0.115	0.0424	0.0106	1640	Oxic	O2
RP-SW-BG	7	0.115	0.641	0.0106	146	Mixed(oxic-anoxic)	O2-Mn(IV)

The calculations were performed in accordance with the *USGS Open File Report 2009-1004, An Excel® Workbook for Identifying Redox Processes in Ground Water* (USGS, 2009).

O2 = dissolved oxygen as O2.

NO3- = dissolved nitrate as nitrogen.

MN2+ = dissolved manganese calculated as 2+ valence.

Fe2+ = dissolved iron calculated as 2+ valence.

SO42- = sulfate 2- ion.

As stated above, oxidation state plays a critical role in uranium mobility in the hydrologic system. Pre-remedial contaminant modeling conducted by Dames and Moore (1983) relied on the assumption that conditions in the pits would stabilize in the anoxic range within a few years so that uranium oxides would stay in the pits. The dissolved oxygen concentrations in the pit waters, not to mention uranium activities four orders of magnitude higher than background, indicate that oxidation reactions are occurring in the pit waters.

Oxidation reactions are also likely occurring where groundwater flows through the 300+ million tons of waste rock re-deposited at the site that are not in the backfilled pits. Much of this material is mapped as being piled along the sides of the pits and Rios Paguate and Moquino; however, there is evidence that the rivers were routinely diverted during mining activities. As a result, much of the original alluvium through the site was excavated in an effort to access the Jackpile Sandstone, and replaced with waste rock (Contact Report #1). This means that the Alluvial Aquifer at the site is flowing through a host material that is at least partially, if not entirely, Jackpile-Paguate waste rock.

4.0 Conceptual Site Model Discussion

4.1 Hydrology

Historical hydrologic data establish that there is hydrologic communication between surface water and both natural groundwater reservoirs (Alluvial and Jackpile) at the site. This observation is based on groundwater and surface water elevation data (Hydro-Search 1979; 1981), aquifer pump tests (USGS, 1983), and hydrologic modeling (Dames and Moore, 1983). Cross sections using historical and recent hydrologic data also support this observation.

The hydrologic models also predict hydrologic communication between backfilled pits and the surface water – groundwater system. Groundwater is predicted to flow from the North Paguate and Jackpile pits into the Alluvial Aquifer, then into the Rio Paguate. Groundwater from the South Paguate Pit is predicted to flow into the Jackpile Sandstone and the Alluvial Aquifer, with some fraction reaching Rio Paguate. This prediction is bolstered by the fact that groundwater levels in several of the wells near the pits have increased up to 66 feet in the last 30 years. The rebound of the water table is due partially to the fact that mining activities, specifically pumping of water from the pit areas, ceased in 1982. Cross sections drawn through the pits illustrate the relationship between the excavated and backfilled pit conditions with respect to the most dramatically affected wells.

The rate of rebound in the pits appears to be much faster than the Dames and Moore (1983) model predicted. This may be in part due to inherent problems with the 2-dimentional model used, or that the assumption that the primary source for rebounding water would be from the Jackpile Sandstone, not the Alluvial Aquifer. The cross sections generated in this report indicate that the North Paguate Pit was likely receiving water from Rio Paguate during the period of rebound (see Cross Section G-G'). The geochemistry of the North Paguate Pit water closely resembles the alluvial/surface water chemistry, both from the 2007 ROD data (OA Systems, 2007) and this report.

4.2 Geochemistry

The historical geochemical data show two populations of natural waters at the site. The surface water and Alluvial Aquifer exhibit a calcium + magnesium – bicarbonate + sulfate chemistry that trends toward sulfate anions as the water system moves downgradient. This is somewhat correlated with the increase in TDS (Hydro-Search, 1981), and the theoretical endmember closely resembles the leachate solutions derived from efflorescent sediments and protore from the site (Hydro-Search, 1981). The shift in chemistry observed in the alluvial/surface water system may be a result of interactions with mineral materials, including re-mobilized efflorescent sediments, alluvium, mine tailings, waste rock, and/or protore.

The Jackpile Aquifer exhibits a sodium + potassium – bicarbonate + sulfate chemistry that is very distinct from the rest of the water system. A few outlier groundwater wells (such as Test Well # 11 from the Hydro-Search, 1979 data set) appear to exhibit mixing with the down-gradient alluvial/surface water endmember. From the 2011 data set, groundwater at MW-1 appears to have drifted from definitively Jackpile chemistry in 2007 toward the down-gradient

alluvial/surface water endmember. This may either reflect some kind of cyclic process that has not yet been identified in the system, or it may reflect a growing chemical influence on the local aquifer.

The pit waters have historically resembled either down-gradient alluvial/surface water (North Paguate Pit, Rabbit Ear Ponds), or Jackpile water (P-10, South Paguate Pit). The new data from the 2011 data set show that the pit waters now all resemble the down-gradient alluvial/surface water endmember, which, as stated above, closely resembles the analyses of solutions derived from the leaching of efflorescent sediments and protore from the site. While not definitive, it seems likely that oxidation reactions in the pit waters (as well as other groundwater in direct contact with waste rock) are the likely culprit for this trend in water chemistry. Cursory inspection of the historical and recent data suggests that this trend may also be occurring in the local surface and groundwater systems outside of the pits; However, more detailed study is needed to determine if this is correct and to identify the cause.

4.3 Uranium Mobilization and Transport

Oxidation reactions between water and waste rock are occurring in the backfilled pits. This is evident not only from direct oxygen and ORP measurements of the pit waters, but from water analyses that show uranium activities that are four orders of magnitude higher than background concentrations in surface water and groundwater above the site. Dissolved oxygen measurements in the pit waters are among the highest recorded at the site, indicating that the pit waters are communicating with atmospheric oxygen. Oxidation-reduction modeling of the pit water samples indicates a co-mingling of waters from oxidizing and reducing conditions, which may indicate some kind of stratification in the pits.

The hydrologic connectivity between the pits and the surface water – groundwater system indicates that contaminants in the pits can migrate into the surface water system. Results from the 2011 ESI indicate that uranium activity increases in all surface water, groundwater, and surface sediment samples as sample locations progress down-gradient through the site. Uranium activity is significantly greater than background in two down-gradient monitoring wells, five down-gradient surface water locations, and three down-gradient sediment locations. This increase in surface water and groundwater contamination has been consistent for every data set collected at the site since 1979 (Hydro-Search, 1979; 1981; Anaconda, 1983; 1985; 1986; OA Systems, 2007; Weston, 2010).

Contamination appears to be leached from the mine waste materials that have been piled along the river systems, used to replace the natural alluvium in places where the river was diverted for the sake of mining, and backfilled into the three main mining pits at the site. Leaching of uranium oxides in the mine wastes is facilitated by the saturation with oxygenated water and the increased surface area of the mineral material due to blasting, crushing, and milling. Contaminants migrate in the dissolved load of groundwater, and they may be dissolved and re-deposited several times due to the high evaporation rates in the vadose zone and in the subaerial environment.

4.4 Natural Sources

The question then becomes whether or not the uranium contamination observed in the surface water, groundwater, and surface sediments is derived from a natural source. While it is probably not possible to rule out a natural source for the entire increase in uranium activity in surface water and groundwater through the site, it is possible to demonstrate that a majority of the contamination is derived from mining activities.

Possible natural sources might include groundwater from the Jackpile Aquifer, naturally exposed surfaces of the Jackpile Sandstone, weathered detritus of Jackpile Sandstone co-mingled with the pre-mining Alluvium, and efflorescent sediments that were deposited by evaporation with the Alluvium during the pre-mining era.

4.4.1 Jackpile Groundwater as a Natural Source of Uranium

Based on historical groundwater sampling data, Jackpile groundwater is an unlikely source of natural uranium contamination. Groundwater monitoring wells located up-gradient of the site, and screened in the Jackpile Aquifer, consistently yield low uranium concentrations and/or activities with respect to down-gradient surface water and groundwater sampling locations (see Table 4 and associated references therein). Field measurements taken during the 2011 ESI indicate that three background wells installed in the Jackpile Aquifer have the lowest dissolved oxygen concentrations of the entire data set. In addition, uranium oxide deposition is known to be intimately associated with concentrations of organic material, especially in the upper portions of the Jackpile Sandstone (Owen, et al., 1984); this organic material may provide additional protection of uranium oxides in the undisturbed form. Regardless, uranium oxides do not appear to be significantly mobile in the Jackpile Aquifer above the site.

4.4.2 Jackpile Outcrops as a Natural Source of Uranium

Exposed surfaces of the Jackpile Sandstone are a probable natural source of uranium into the surface water system. Physical and chemical weathering of the Jackpile Sandstone would liberate the uranium oxides, which would then enter the surface water system when exposed to meteoric water. This process would probably occur slowly, and the area of activity would be limited to the naturally exposed wall and some reaction depth into the outcrop. Such exposed surfaces are the likely source of the radiation signature that drew mining interests to the area in the first place (Owen, et al., 1984).

There are natural Jackpile Sandstone surfaces exposed in the walls of Oak Canyon and a few other isolated locations along the mesa walls, but most of these exposures have been altered by mining activities within this watershed. The Anaconda Mineral Company disturbed approximately 356 million tons of rock, and exposed over 2 square miles of Jackpile Sandstone surface in this watershed. Much of this has occurred where the Jackpile Sandstone is intersected by Rios Paguate and Moquino. The proportional contribution of this increased, anthropogenic exposure, including the increased surface area of the waste rock, protore, and tailings piles, is expected to be overwhelmingly higher than from the exposed natural surfaces.

4.4.3 Weathered Jackpile Detritus as a Natural Source of Uranium

Weathered Jackpile Sandstone is an unlikely source of significant quantities of uranium in the surface water system. The weathering process would include physical ablation of the sandstone and fairly rapid chemical leaching of the uranium oxide cements into the surface water system. The Jackpile Sandstone is also very friable, so coherent sandstone fragments are not likely to survive more than a few hundred feet of transport. It is therefore unlikely that any remnant Jackpile Sandstone clasts would survive in sufficient quantities to provide a source in the Alluvium capable of affecting surface water and/or groundwater chemistries. Added to this is the fact that any place where such deposits might have existed would have been deposited in the Alluvium very near where the strike of the Jackpile Sandstone is cut by the Rios Paguate and Moquino systems. Since this is where mining activities were focused, any significant accumulations of deposits would have been scraped out by Anaconda during mining operations and replaced with waste rock.

4.4.4 Efflorescent Deposits as a Natural Source of Uranium

Efflorescent deposits are the precipitated salts formed as a result of the evaporation of surface and vadose water that contains a high dissolved sediment load. The TDS for surface waters collected near the site during the 2011 ESI range from 420 to 3,860 mg/l, and the TDS for groundwater samples collected at the site during the same event range from 515 to 3,500 mg/l (up to 6,370 mg/l in the Jackpile Pit water). Under oxidizing conditions (subaerial and oxic groundwater conditions and pH in the normal range), uranium oxides are very soluble, and will only precipitate under evaporitic conditions, which occur during periods of low flow. During periods of high-water flow, these deposits are quickly re-dissolved and mobilized. Qualitative evidence of this may be found in that sediment cores collected during the 2010 SI did not yield significantly elevated uranium concentrations, but the targeted surface sampling during the 2011 ESI did find significantly elevated uranium activities. Soluble minerals can be transported downstream in multiple iterations of dissolution and precipitation. Because of the high solubility of these deposits, they are ephemeral and tend to be washed out during periods of high rain/ water flow.

For the efflorescent sediments collected during the 2011 ESI, uranium activities are significantly elevated with respect to background in samples collected at three locations. These are all surface samples, and therefore unlikely to have survived 60 years of seasonal flooding.

The highest activity in sediment (RM-JM = 11.9 picoCuries per kilogram) is reported at a location where much of the natural alluvium has been co-mingled with, or replaced with waste rock from mining activities. The uranium in these sediments represents new, post-mining deposition, not residual, natural efflorescence from the weathering of Jackpile Sandstone during pre-mining activities.

It should also be noted that the uranium activities in the sediments are commonly an order of magnitude lower than the uranium activities in the co-located water sediments, which makes it very difficult to make the argument that these sediments are responsible for the observed uranium activities in the surface water and groundwater systems.

It is not possible to completely rule out the existence of residual, pre-mining-era efflorescent sediments in the alluvial/surface water system, but their vulnerability to dissolution during high-water events makes their survivability in any substantial volume that is capable of producing the concentrations of uranium in an active fluvial system unlikely.

5.0 Conclusions

The Jackpile-Paguate site operated as a uranium mine from the period 1953 to 1982. During mining activities, 356 million tons of material were disturbed, and 22 million tons of ore were removed from the site. The property on which the former uranium mine is located encompasses approximately 7,868 acres. Approximately 2,656 acres of this property were disturbed by mining operations and contained three open pits that were between 200 and 300 feet deep; 32 waste dumps; and 23 protore stockpiles.

Reclamation efforts began with the Anaconda Minerals Company and reverted to the Pueblo of Laguna Tribe in 1985. Reclamation efforts included backfilling the excavation pits with tailings, waste rock, and protore, as well as grading and capping various waste materials. Post-reclamation monitoring efforts included surface water and groundwater sampling efforts.

The START-3 conducted a review of hydrologic and geochemical data files available from BLM and the Pueblo of Laguna and conducted an ESI sampling event at the site in May 2011 on behalf of EPA Region 6 at the site. The ESI sampling included the collection of groundwater, surface water, and surface sediments that were submitted to an EPA-approved laboratory for general water quality analyses (metals, anions, TDS), as well as radionuclides. Field water quality measurements, including pH, temperature, specific conductivity, dissolved oxygen, and Oxidation-Reduction Potential, were collected at the time each sample was collected. groundwater elevation measurements were also collected from a wider suite of wells to gain a better understanding of the overall groundwater system.

Based on data culled from several hydrologic studies from 1979 to the present, as well as the results of the 2011 ESI, the groundwater and surface water systems of the site may be described as follows:

- Hydrologic data indicate that both surface water and groundwater flow from east-northeast to west-southwest in the western half of the study area, and from north to south in the eastern half of the study area.

- General cation/anion chemistry identifies two distinct populations of water – one is a Na + K – bicarbonate-sulfate water that is associated with the Jackpile Sandstone, and the other is a Ca + Mg – carbonate-bicarbonate-sulfate water associated with the Alluvial Aquifer and surface water systems. Strong similarities between the surface water and alluvial groundwater strongly suggest that these populations are in intimate contact across the site.

- Uranium concentrations/activities increase with respect to background in both groundwater and surface water across the site. This is demonstrated in the results of the 2011 ESI sampling event, as well as at least four studies involving surface water (Hydro-Search 1979; 1981; OA Systems, 2007, Weston 2010, Laguna 2010), and two studies involving groundwater (Hydro-Search 1979; 1981; OA Systems, 2007).

- Groundwater, surface water, and sediment samples collected on-site and downgradient of the site have uranium activities that are significantly elevated with respect to background above the site.

Historical data establish that there is hydrologic communication between surface water and both natural groundwater reservoirs (Alluvial and Jackpile) at the site. This observation is based on groundwater and surface water elevation data, aquifer pump tests, and hydrologic modeling. Cross sections using historical and recent hydrologic data from the 2011 ESI event also support this observation.

Field measurements and laboratory analysis of the groundwater in the Jackpile, North Paguate, and South Paguate pits indicate that chemical reactions are occurring in the backfill that mobilize uranium in very high concentrations (four to five orders of magnitude higher than background surface or groundwater). Groundwater in the pits appears to be rebounding at a rate much higher than pre-remedial modeling predicted; groundwater in the South Paguate Pit has already rebounded 10 feet above the elevation it was projected to reach after 150 years (Dames and Moore, 1983). Hydrologic observations and modeling indicate that these pit waters are not contained and will flow into the surface water system via groundwater pathways, carrying contaminants into that system.

The primary source of uranium in surface and groundwater on-site, and down-gradient of, the Jackpile-Paguate Mine Site is thought to be the approximately 356 million tons of waste rock, tailings, and protore at the site that are in intimate contact with the surface water and groundwater system. While natural sources cannot be completely ruled out, existing data have yet to identify a source with the volume and contaminant concentration capable of producing the observed impact to surface water and groundwater system.

Chemical data also suggest that reactions in the backfilled pits, and subsequent migration to groundwater, may be shifting the chemistry of surface water at, and below the site. The actual extent to which that is happening would require a more detailed analysis of the existing historical data, as well as a more coordinated synthesis of the surface water and groundwater data being collected at the site.

6.0 References

Anaconda, 1983. Data Transmission Letters. Prepared by Anaconda Copper Company, presented to Superintendent, Laguna Agency, Bureau of Indian Affairs, US Department of Interior, 1983.

Anaconda, 1985. Data Transmission Letters. Prepared by Anaconda Copper Company, presented to Superintendent, Laguna Agency, Bureau of Indian Affairs, US Department of Interior, 1985.

Anaconda, 1986. Data Transmission Letters. Prepared by Anaconda Copper Company, presented to Superintendent, Laguna Agency, Bureau of Indian Affairs, US Department of Interior, 1986.

Beck, et al., 1979. Jackpile-Paguate Deposit – A Review. By R. G. Beck, C.H Cherrywell, D.F. Earnest, and W.C. Feirn, in Geology and Mineral Technology of the Grants Uranium Region, 1979, Christopher A. Rautman, Editor; New Mexico bureau of Mines and Mineral Resources, Memoir 38, 1980.

Brookins, 1979. Geochronologic Studies in the Grants Mineral Belt. Douglas G. Brookins, in Geology and Mineral Technology of the Grants Uranium Region, 1979, Christopher A. Rautman, Editor; New Mexico bureau of Mines and Mineral Resources, Memoir 38, 1980.

Dames and Moore, 1980. Report: Geotechnical Consultation Sedimentation in Paguate Reservoir, South of Jackpile Mine Near Laguna, New Mexico. Prepared by Dames and Moore, Inc. for Anaconda Copper Company, January 9, 1980.

DoI, 1985. Jackpile Paguate Mine Site Visual A. Map of Jackpile Paguate Mine with Source identified as "Modified from Anaconda Minerals Co. 1982. US Department of the Interior, Bureau of Land Management, Albuquerque District, 1985.

DoI, 1986. Jackpile-Paguate Uranium Mine Reclamation Project Environmental Impact Statement. Volume 1. United States Department of Interior, October 1986.

Hydro Geo Chem, 1982. Effects of Uranium Mine Dewatering on the Water Resources of the Pueblo of Laguna, New Mexico. By Hydro Geo Chem., Inc., prepared for Pueblo of Laguna, Laguna, New Mexico, march 15, 1982.

Hydro-Search, 1979. Hydrogeologic Relationships: Rabbit Ear an dP-10 Holding Ponds Jackpile-paguate Mine, Valencia County [sic], New Mexico. Prepared by Hydro-Search, Inc. for Anaconda Copper Company, June 15, 1979.

Hydro-Search, 1981. Hydrology of the Jackpile-Paguate Mine Area, New Mexico. Prepared by Hydro-Search, Inc. for Anaconda Copper Company, June 15, 1981.

OA Systems, 2007. Jackpile-Paguate Uranium Mine Record of Decision Compliance, Post-Reclamation Water Quality Data Review. Prepared by OA Systems Corporation, June 2007.

Owen, et. al., 1984. The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico – a Formal Definition. Donald E. Owen, Lester J. Walters, Jr., and Ronald G. Beck. In New Mexico Geology, Vol. 6, No. 3, pp. 45-52, August 1984.

Park and MacDiramid, 1975. Ore Deposits. Charles F. Park and Roy A. MacDiramid, Third Edition, W. H. Freeman and Company, San Francisco, 512 p., 1975.

Pueblo of Laguna, 2010. Data Transmission: 2010 Final Uranium Results. Correspondence and Attached Excel Spreadsheet from Curtis L. Francisco, Pueblo of Laguna Water Quality Specialist to Brenda Cook and LaDonna Turner, US EPA Region 6 Superfund Division, December 14, 2010.

USGS, 1957a. Moquino, New Mexico 7.5-Minute Topographic Series Map, United States Geological Survey, 1957.

USGS, 1960. Mesita, New Mexico 7.5-Minute Topographic Series Map, United States Geological Survey, 1960.

USGS, 1957b. Dough Mountain, New Mexico 7.5-Minute Topographic Series Map, United States Geological Survey, 1957.

USGS, 1963a. Geologic Map of the Laguna Quadrangle, New Mexico, mapped by Robert H. Moench, United States Geological Survey, 1963.

USGS, 1963b. Geologic Map of the Moquino Quadrangle, New Mexico, mapped by Robert H. Moench, United States Geological Survey, 1963.

USGS, 1963c. Geologic Map of the Mesita Quadrangle, New Mexico, mapped by Robert H. Moench, United States Geological Survey, 1963.

USGS, 1963d. Geologic Map of the Seboyeta Quadrangle, New Mexico, mapped by Robert H. Moench, United States Geological Survey, 1963.

USGS 1984. Aquifer Tests at the Jackpile-Paguate Uranium Mine, Pueblo of Laguna, West-Central New Mexico. By Dennis W. Risser, Paul A Davis, Joe A Baldwin, and Douglas P. McAda, United States Geological Survey Water-Resources Investigations Report 84-4255, 1984.

USGS 1985. Hydrology and Water-Quality Monitoring Considerations, Jackpile Uranium Mine, Northwestern New Mexico. By Harold H Zehner, United States Geological Survey Water-Resources Investigations Report 85-4226, 1985.

USGS, 2009. An Excel® Workbook for Identifying Redox Processes in Ground Water. USGS Open File Report 2009-1004.

Weston, 2010. Draft Site Inspection Report for Jackpile-Paguate Uranium Mine, SR 279, Near Paguate, Laguna Pueblo Paguate, Cibola County, New Mexico. Prepared by the Superfund Technical Assessment and Response Team, Weston Solutions, Incorporated; prepared for United States Environmental Protection Agency, Region 6, Superfund Division, Site Assessment Office, June 2010.

Weston, 2011. Draft Jackpile-Paguate Conceptual Site Model v.1. Prepared by the Superfund Technical Assessment and Response Team, Weston Solutions, Incorporated; prepared for United States Environmental Protection Agency, Region 6, Superfund Division, Site Assessment Office, January 2011.

New Mexico GEOLOGY
• Science and Service
Volume 6, No. 3, August 1984

The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico—a formal definition

by *Donald E. Owen*, Consulting Geologist, Tulsa, OK 74152, and *Lester J. Walters, Jr.* and *Ronald G. Beck*, ARCO Oil and Gas Co., Dallas, TX 75221

The Jackpile Sandstone Member of the Morrison Formation (Upper Jurassic) in west-central New Mexico is named here formally from a stratotype near the Jackpile–Paguate uranium mine. The Jackpile Sandstone is typically a whitish, crossbedded subarkose with clay matrix and interbedded, variegated, pale-green to red, bentonitic mudstone lenses. Contacts with the underlying Brushy Basin Member of the Morrison Formation may be gradational, scoured, or interbedded. The Jackpile extends only a short distance south of the stratotype due to truncation along the basal Dakota unconformity. However, it extends northeast to Lamy, north to near Cuba, and a short distance west and a longer distance northwest into the subsurface of the San Juan Basin. Thickness of the Jackpile ranges from near zero to 300 ft (91 m); at the stratotype it is 100 ft (30 m) thick. Crossbedding indicates a regional easterly paleocurrent-flow direction for the braided-stream and distal alluvial-fan complexes in which the Jackpile was deposited. Source areas were to the west and southwest, south of Gallup, and in the Mogollon Highlands.

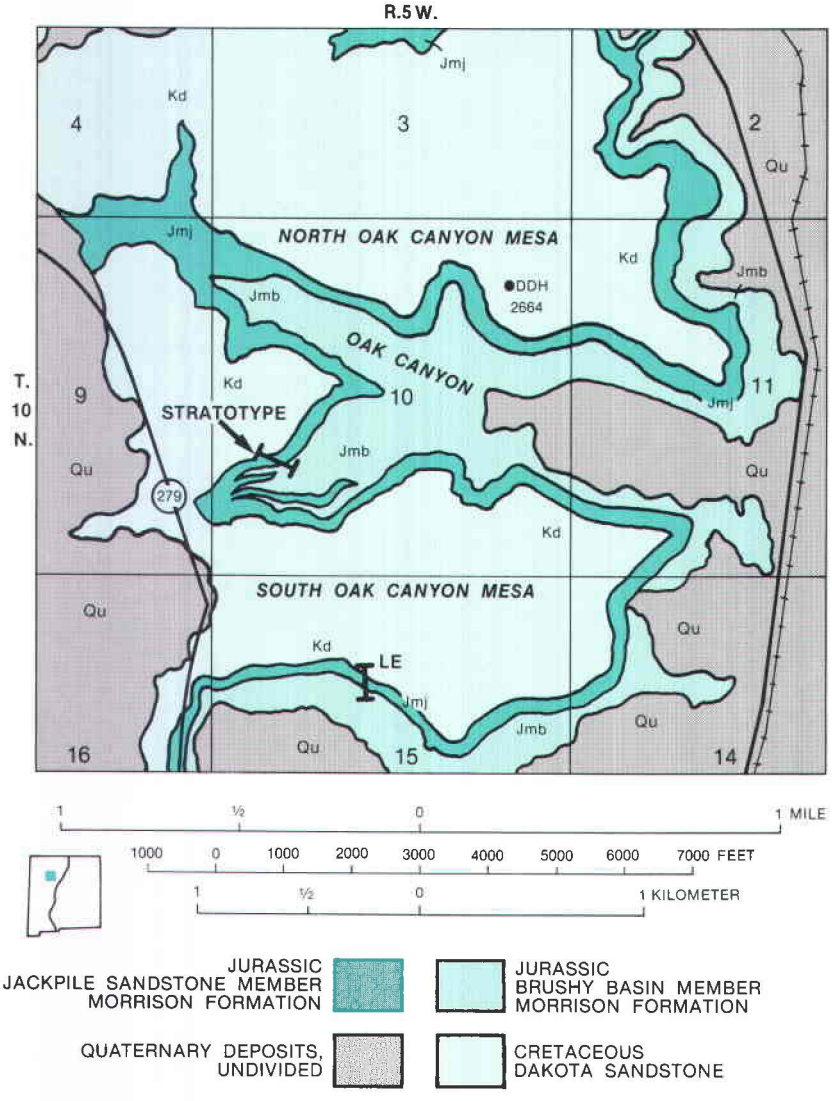


FIGURE 1—Geologic index map of the stratotype area of the Jackpile Sandstone Member (Morrison Formation). Note location of surface measured section illustrated in Fig. 2 and subsurface reference section (DDH 2664) illustrated in Fig. 3. **LE** is the location of an additional measured section. The map has been simplified and modified from Schlee and Moench (1963b); small igneous dikes and sills have been omitted.

Introduction

The Jackpile sandstone of economic usage has been employed informally in stratigraphic nomenclature for a distinctive bed in the uppermost part of the Brushy Basin Member of the Morrison Formation in west-central New Mexico since the Jackpile uranium body was discovered in that bed during 1951. The stratigraphic name Jackpile has ☞

Also in this issue

Coming soon

Fossil rock glaciers on Carrizo Mountain
Adobe as a building material
Dinosaurs from the McRae Formation, Sierra County
Morphy Lake State Park

350002799

appeared in many publications in various forms since its first published use by Freeman and Hilpert (1956). The Jackpile sandstone appears on many geologic maps (e.g., Schlee and Moench, 1963a, b), in many government reports (e.g., Moench and Schlee, 1967; Santos, 1975), and in several correlation diagrams (e.g., Owen and Siemers, 1977; Maxwell, 1982). In spite of its use, the Jackpile sandstone has never been named formally. Nash (1968, p. 738) used the term Jackpile ". . . as if a Morrison member." The late Gary Flesch suggested that the Jackpile should be a formal member of the Morrison Formation and established two reference sections for it, but he did not actually formalize it (Flesch, 1974; 1975).

The purposes of this paper are to designate the Jackpile Sandstone Member of the Morrison Formation as a formal stratigraphic unit meeting the requirements of the new North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983) and to discuss the deposition of the Jackpile Sandstone.

Nomenclature and location

The Jackpile Sandstone is named for the Jackpile mine that was opened in the SE1/4 sec. 35, T. 11 N., R. 5 W., Cibola (formerly Valencia) County, New Mexico. The contiguous Jackpile–Paguate mine is the world's largest uranium mine; 24.1 million metric tons (26.51 million short tons) of uranium ore were shipped between 1954, when the mine opened, and 1982, when the mine closed (McLemore, 1982). The stratotype for the Jackpile Sandstone is a measured section of a surface outcrop in SE1/4 NW1/4 SW1/4 sec. 10, T. 10 N., R. 5 W., Mesita 7 1/2-min quadrangle (Fig. 1). This location is approximately 2.5 mi (4 km) southwest of the original mine opening. The section (Fig. 2; Table 1) was measured on a series of south-facing cliffs north of the south fork of Oak Canyon. These cliffs occur on the face of an unnamed triangular mesa between South Oak Canyon Mesa and North Oak Canyon Mesa at a point 0.3 mi (0.5 km) east of NM–279. A subsurface reference section (Fig. 3) also is provided from a core and log taken in Anaconda Diamond Drill Hole 2664 in SW1/4 NE1/4 NE1/4 of the same section, approximately 0.8 mi (1.3 km) northwest of the stratotype (Fig. 1). Flesch (1974, 1975) suggested two reference sections farther to the north that also are available for study. His 1975 section was published in Siemers et al. (1975, p. 30).

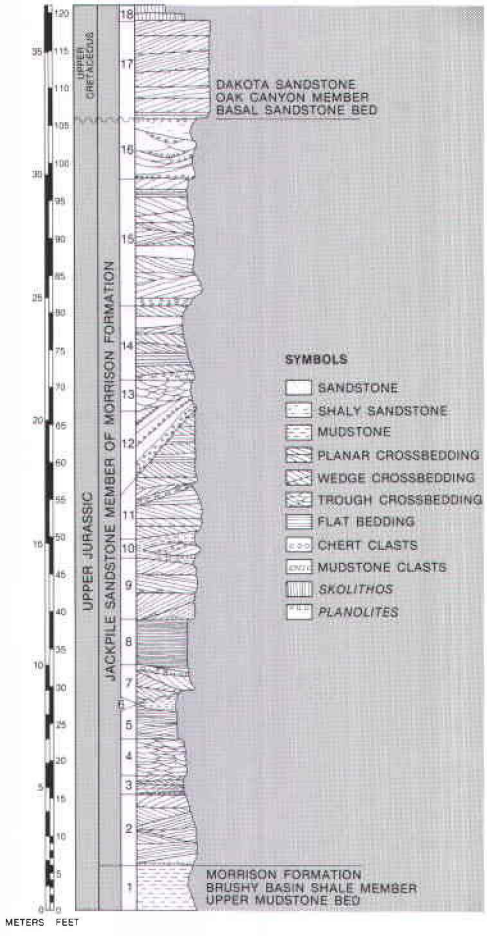


FIGURE 2—Graphic measured section of the Jackpile Sandstone Member (Morrison Formation) and adjacent units at the stratotype. See Table 1 for description of units and Fig. 1 for location of stratotype.

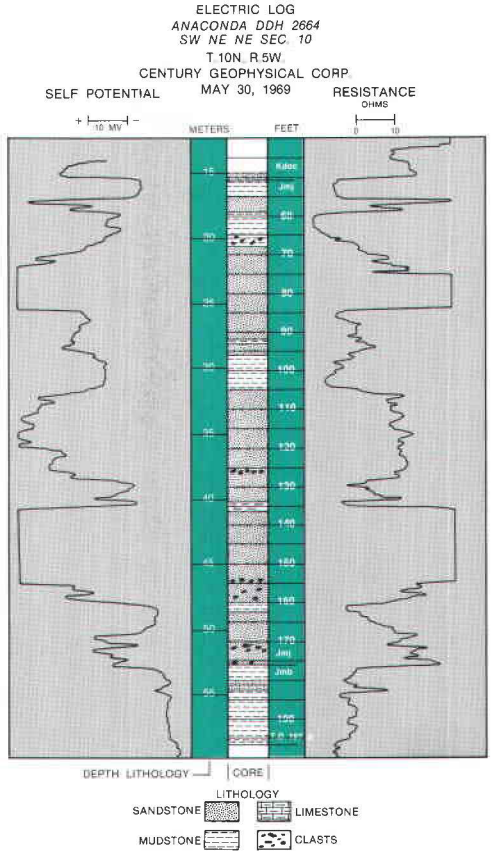


FIGURE 3—Electrical log and core log of the Jackpile Sandstone and adjacent units at the subsurface reference section. See Fig. 1 for location of DDH 2664. "Squared off" ends of spontaneous potential and resistance traces indicate off-scale readings. **Kdoc** is the Oak Canyon Member of Dakota Sandstone; **Jmj** is the Jackpile Sandstone Member of Morrison Formation; **Jmb** is the Brushy Basin Member of Morrison Formation.

Following established informal usage, the Jackpile Sandstone Member of the Morrison Formation is split from the underlying Brushy Basin Member. The Brushy Basin is the most extensive member of the Morrison, being present over nearly all of the Colorado Plateau (Craig et al., 1955, p. 155). At the stratotype, the Jackpile is overlain unconformably by the basal sandstone bed of the Oak Canyon Member of the Dakota Sandstone, which forms the rimrock in all of Oak Canyon (Fig. 4).

Description

Lithology

The Jackpile Sandstone varies considerably in detailed lithology. Typically, it is an off-white to yellowish-tan, crossbedded, friable, subarkosic sandstone with mostly medium and coarse, subangular to well-rounded, poorly to well-sorted grains in a white clay matrix. The white clay matrix, which is a distinctive feature of the Jackpile, is mostly kaolinite. Some beds are very coarse grained and a few, chiefly at the base of scour surfaces, contain a few pebbles, mostly of chert. Chert-pebble zones are more common in the southwest part of the Jackpile distribution, in the vicinity of the stratotype, than to the north and east. Some Jackpile beds are fine-grained sandstone, but very fine grained sandstone and siltstone beds are rare. Porosity ranges from near 0% to 20% or more and varies inversely with clay-matrix content. Most outcrops contain a few thin lenses and beds of variegated, pale-green to red,

New Mexico GEOLOGY

• Science and Service

Volume 6, No. 3, August 1984

published quarterly by
New Mexico Bureau of Mines and Mineral Resources
a division of New Mexico Institute of Mining & Technology

Subscriptions: Issued quarterly, February, May, August, November; subscription price $6.00/yr.

Editorial matter: Contributions of possible material for consideration in future issues of NMG are welcome. Articles submitted for publication should be in the editor's hands a minimum of five (5) months before date of publication (February, May, August, or November). Address inquiries to Deborah A. Shaw, editor of *New Mexico Geology*, New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801

Circulation: 1,400

Printer: University of New Mexico Printing Plant

TABLE 1—LITHOLOGIC DESCRIPTION OF JACKPILE SANDSTONE STRATOTYPE. Unit numbers correspond to numbers in Fig. 2.

Unit	Description	Thickness
	Dakota Sandstone:	
	basal sandstone bed of Oak Canyon Member:	
18	Sandstone (quartz arenite), tan, weathers rusty brown; very fine to fine grained, well sorted, subangular to rounded; iron oxide and silica cement; thinly to poorly bedded (partially bioturbated); abundant *Skolithos* burrow fillings; sharp, planar lower contact; eroded back from canyon rim	2 ft (0.6 m)
17	Sandstone (quartz arenite), tan, weathers rusty brown; very fine to fine grained, well sorted, subangular to rounded; silica cement; carbonaceous; medium-scale planar crossbedding; abundant *Planolites* burrow fillings in lower 4 inches (10 cm) that extend into unit below; planar, unconformable lower contact; forms canyon rimrock	13 ft (4 m)
	Total thickness	15 ft (4.6 m)
	Morrison Formation:	
	Jackpile Sandstone Member:	
16	Sandstone (lithic subarkose), greenish-gray, fresh and weathered; medium to coarse grained, fines upward, poorly to very poorly sorted, subrounded to rounded; abundant clay matrix, especially in upper part; subrounded to rounded chert pebbles throughout, angular sandstone pebbles and cobbles in upper part, abundant kaolinized feldspar grains; medium-scale trough crossbedding, except in upper clayey part; gradational lower contact; recedes under canyon rimrock above	8 ft (2.4 m)
15	Sandstone (subarkose), off-white, weathers tan; medium to coarse grained, moderately to poorly sorted, angular to rounded; abundant clay matrix; planar and wedge crossbedding with some massive beds; one fining-upward sequence at base with basal chert pebbles and mudstone clasts; sharp, irregular lower contact; moderately resistant	17 ft (5.2 m)
14	Sandstone (subarkose), tan, fresh and weathered; fine to coarse grained, moderately to poorly sorted, subangular to rounded; clay matrix; mudstone clasts and chert pebbles in basal bed; small and medium-scale planar crossbedding and massive beds; one fining-upward sequence at base; sharp lower contact; moderately resistant	10 ft (3 m)
13	Sandstone (subarkose), off-white, weathers tan; fine to medium grained, moderately to poorly sorted, subangular to subrounded; clay matrix; small-scale trough crossbedding; sharp, uneven lower contact; moderately resistant	2–4 ft (0.6–1.2 m)
12	Sandstone (subarkose), off-white, weathers tan; fine to very coarse grained, poorly to moderately sorted, subangular to rounded; clay matrix; chert pebbles, especially in lower 3 ft (0.9 m); medium-scale planar crossbedding; sharp, planar lower contact; moderately resistant	2–9 ft (0.6–2.7 m)
11	Sandstone (subarkose), off-white, weathers tan; fine to coarse grained, well to poorly sorted, subrounded to rounded; clay matrix; mudstone cobble zone near middle; medium-scale planar crossbedding and laminated flat bedding; sharp lower contact; moderately resistant	8–16 ft (2.4–4.9 m)
10	Mudstone, grayish-green, fresh and weathered; silty, sandy, mudstone-clast conglomerate in part; sharp lower contact; non-resistant; with sandstone wedge (subarkose), light tan, weathers light brown; very fine to medium grained, well sorted, subrounded to rounded; clay matrix; few chert pebbles; composed of one set of wedge crossbedding; sharp lower contact; moderately resistant	2.5–4.5 ft (0.8–1.4 m)
9	Sandstone (arkose), light-tan, weathers dark tan; medium to coarse grained, several fining-upward sequences, moderately to poorly sorted, subangular to subrounded; clay matrix; few mudstone clasts; medium-scale wedge and planar crossbedding; sharp, planar lower contact; moderately resistant	8 ft (2.4 m)
8	Sandstone (subarkose), off-white, weathers tan; very fine to medium grained, well to moderately sorted, angular to rounded; clay matrix; thinly flat-bedded, changes to crossbedded to west; sharp, planar lower contact; weakly resistant	6.5 ft (2m)
7	Sandstone (lithic subarkose), off-white, weathers light brown; medium to very coarse grained, moderately to poorly sorted, angular to rounded; clay matrix; abundant mudstone clasts up to 6 inches (15 cm) diameter in bed near top; medium-scale, planar to wedge crossbedding; load casts on base with up to 1 ft (0.3 m) relief; sharp, very uneven lower contact	3–5 ft (0.9–1.5 m)
6	Mudstone, grayish-green, fresh and weathered; silty, sandy, feldspathic, common glass shards; thinly bedded; sharp, irregular lower contact; nonresistant	0–3 ft (0–0.9 m)
5	Sandstone (subarkose), yellowish-tan, weathers light brown; fine to coarse grained, poorly sorted, subangular to rounded; clay matrix; medium-scale planar crossbedding and flat bedding; sharp, flat lower contact; moderately resistant	3–5 ft (0.9–1.5 m)
4	Sandstone (arkose), very light tan, fresh and weathered; fine to very coarse grained, moderately to poorly sorted, subangular to subrounded; clay matrix; quartz overgrowths; small-scale trough crossbedding, gradational lower contact; moderately resistant	5 ft (1.5 m)
3	Sandstone (subarkose), light yellowish-tan, fresh and weathered; fine to coarse grained, several fining-upward sequences, well to poorly sorted, subrounded to rounded; clay matrix; chert pebbles near base; small-scale planar crossbedding; sharp, flat lower contact; weakly resistant	2.5 ft (0.8 m)
2	Sandstone (arkose), light yellowish-tan, fresh and weathered; fine to very coarse grained, moderately to poorly sorted, angular to rounded; clay matrix; basal chert pebble and mudstone clast zone; low-angle, medium-scale wedge crossbedding; sharp, uneven (scoured) lower contact changing to gradational to west; weakly resistant	9.5 ft (2.9 m)
	Total thickness	100 ft (30.5 m)
	Morrison Formation:	
	upper mudstone bed of Brushy Basin Member:	
1	Mudstone, grayish-green, weathers light grayish-green; silty, sandy; poorly bedded, fractured; lower contact concealed; non-resistant	6 ft (1.8 m)
	Total thickness	6 ft (1.8 m)

350002801

FIGURE 4—View of the Jackpile Sandstone and adjacent units at the stratotype. Person is standing on upper part of Brushy Basin Member. Dark rimrock at skyline is basal Oak Canyon Member of Dakota Sandstone. Light-colored cliffs are Jackpile Sandstone Member (thickness: 100 ft; 30 m).

bentonitic mudstone. Locally, these may be thick and extensive. Mudstone clasts are fairly abundant in some sandstone beds and range from pebble to boulder size.

At the stratotype, Jackpile sandstones have an average composition of 58% quartz and chert, 16% feldspars, 5% rock fragments, and 21% clay matrix, based on point counts of 22 thin sections for major components (Table 2; Fig. 5). Significant minor components include very fine crystalline pyrite, organic carbonaceous material not recognized easily in hand specimens, iron oxide, and iron carbonate minerals. Of the 22 samples, 15 are subarkoses according to the classification of McBride (1963). Average porosity by point count is 10%.

Contacts

The contacts of the Jackpile Sandstone Member with adjacent stratigraphic units are distinct and easily recognized in outcrops and cores, but not so easily recognized on well logs. The basal contact with the Brushy Basin Member is well marked by a color and lithologic change from green and red mudstone to off-white to yellowish-tan sandstone (Fig. 6). At most localities this lithologic change is gradational through a few inches; at some localities the contact is sharp and scoured; and at a few localities, intertonguing of Brushy Basin mudstone and Jackpile sandstone takes place within a few tens of feet. Schlee and Moench (1963b) mapped such an intertonguing just west and south of the stratotype in the same quarter section (Fig. 1).

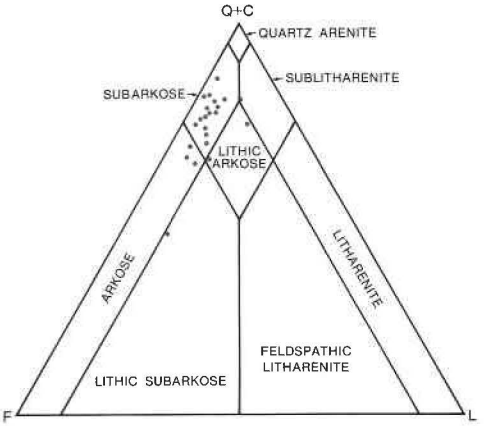


FIGURE 5—Plot of classification of Jackpile Sandstone samples from the stratotype. The sandstone classification is from McBride (1963). The Jackpile sandstones are predominantly subarkosic (15 of 22 samples).

The upper contact of the Jackpile Sandstone with the Dakota Sandstone is an easily recognized unconformity with a typical lithologic and color change from the light-colored, near-white Jackpile sandstone to the darker colored, commonly iron-oxide-stained Dakota sandstone (Fig. 7). A very thin conglomerate or pebbly sandstone bed is fairly common on the unconformity. The basal Da-

TABLE 2—Modal compositions of the Jackpile Sandstone at the stratotype.

	Constituents (%)													
Sample (unit)	Quartz	Chert	Plagioclase	K-Feldspar	Rock fragments	Clay[1]	Porosity	Heavy minerals	Biotite	Calcite	Iron oxide/ iron carbonate	Pyrite/ OCM[2]	Total	Points counted
1(1)	42.4	1.0	5.6	3.4	1.0	41.2	tr	1.0	tr	0.0	4.6	1.0	101.2	323
2(2)	47.0	2.9	10.8	3.5	1.3	30.2	1.0	tr	0.0	0.0	0.0	2.9	99.6	315
3(2)	39.7	4.0	9.0	9.3	5.7	10.7	18.0	0.0	0.0	2.0	1.3	tr	99.7	300
4(2)	31.2	1.3	17.2	12.7	7.1	15.3	12.3	1.0	0.0	tr	1.9	tr	100.0	308
5(3)	57.7	1.0	12.5	5.1	2.5	2.9	15.1	tr	0.0	0.0	tr	2.6	99.4	312
6(4)	52.1	1.0	16.5	3.6	3.6	4.6	14.2	1.0	tr	0.0	1.6	1.6	99.8	303
7(5)	50.2	1.6	10.5	1.6	3.3	13.8	8.8	tr	1.0	0.0	5.9	3.6	100.3	305
8(6)	21.0	4.8	4.8	0.0	0.0	66.3	1.6	0.0	1.0	0.0	tr	tr	99.5	309
9(7)	41.5	2.6	11.3	5.0	7.4	15.3	9.3	0.0	tr	tr	1.0	6.3	99.7	301
10(8)	48.9	tr	10.5	1.6	3.3	15.4	14.1	0.0	tr	0.0	1.0	4.9	99.7	305
11(9)	41.3	1.2	14.9	3.5	3.9	4.8	1.6	1.0	0.0	0.0	16.2	11.7	100.1	315
12(10)	51.8	1.3	10.2	2.0	3.3	10.2	12.5	tr	0.0	0.0	0.0	8.5	99.8	305
13(11)	45.8	1.0	10.4	2.6	3.9	13.6	7.8	0.0	tr	0.0	0.0	14.9	100.0	308
14(11)	56.4	1.6	9.0	3.2	4.5	8.0	16.3	0.0	tr	0.0	0.0	1.0	100.0	312
15(11)	48.0	3.9	7.2	2.9	2.0	8.5	17.0	0.0	tr	0.0	9.1	1.0	99.6	306
16(11)	49.8	2.2	13.8	1.3	6.1	11.2	12.9	0.0	tr	0.0	1.3	1.3	99.9	311
17(12)	51.3	1.2	6.7	3.8	4.2	12.8	18.3	0.0	0.0	0.0	0.0	1.6	99.9	312
18(13)	61.4	2.6	7.5	1.3	2.3	9.1	10.4	0.0	1.0	0.0	0.0	4.9	100.5	308
19(14)	44.7	2.0	11.3	3.6	5.8	18.8	9.1	0.0	0.0	0.0	0.0	4.8	100.1	301
20(15)	52.4	1.6	8.4	1.9	3.2	20.4	3.6	0.0	0.0	0.0	2.6	5.8	99.9	309
21(15)	46.6	2.0	6.2	1.6	4.6	28.5	7.5	0.0	0.0	0.0	0.0	2.9	99.9	305
22[3](16)	48.6	4.5	3.7	3.7	11.1	28.4	—	0.0	0.0	0.0	0.0	0.0	100.0	109
Mean	46.8	2.0	9.9	3.5	4.0	17.7	10.0	tr	tr	tr	4.2	3.7	99.9	
Dakota Sandstone														
23(17)	65.3	1.6	1.6	0.0	tr	0.0	tr	0.0	0.0	0.0	0.0	31.5	100.0	311
24(18)	82.4	0.0	1.0	0.0	0.0	7.1	7.8	0.0	0.0	0.0	1.0	1.0	100.3	307

Notes: 1. Includes clay pore fillings, clay rims, and matrix
2. OCM = Organic carbonaceous material
3. Grain mount, porosity was not determined

350002802

FIGURE 6—Brushy Basin–Jackpile contact at the stratotype. Note the ledge of Jackpile Sandstone resting on fractured Brushy Basin mudstone.

FIGURE 7—Jackpile–Dakota contact at the stratotype. The contact, an unconformity, is at the color change from light-colored Jackpile to dark-colored Dakota midway on hammer handle. The Dakota is characteristically more resistant than the Jackpile and forms an overhanging ledge.

kota is a fluvial-channel sandstone at some localities and a transgressive-marine sandstone with sand-filled burrows of *Planolites* extending down a few inches into the Jackpile at other localities, including the stratotype (Fig. 8). The uppermost Jackpile may be green or red mudstone instead of sandstone at some localities. Rarely, a basal Dakota sandstone bed is not present, which leaves a black, carbonaceous shale of the Dakota resting directly on the unconformity.

Recognition of the Jackpile Sandstone Member contacts on subsurface well logs is difficult. The basal Jackpile contact is fairly easy to recognize due to the deflection to the left of spontaneous potential (S.P.) and gamma-ray curves and an increase in resistivity due to the lithologic change from Brushy Basin mudstone to Jackpile sandstone (Fig. 3). However, because the lower Jackpile locally intertongues with the upper Brushy Basin, because mudstone lenses occur in the Jackpile, and because channel-sandstone lenses occur in the Brushy Basin, the exact location of the contact on some well logs is debatable.

FIGURE 8—Close-up view of sand-filled *Planolites* burrows on Dakota–Jackpile unconformity. The burrow fillings are approximately 1 inch (2.5 cm) in diameter.

The Jackpile–Dakota contact, an unconformity, does not register distinctly on well logs because it is generally a sandstone–sandstone contact. It can be correlated with some uncertainty. However, in the subsurface reference drill hole (Fig. 3) the uppermost Jackpile is mudstone and the lowermost Dakota is sandstone, so that the contact may be placed at the S.P. and resistivity deflections.

Distribution

The extent of the Jackpile Sandstone to the south, southwest, and southeast of the stratotype is closely limited by truncation along the basal Dakota unconformity. Accordingly, the Jackpile is not present south of the Rio San Jose valley (Fig. 9) southwest of the stratotype (Moench, 1963; Moench and Schlee, 1967, pl. 3). The Jackpile also is truncated southeast of the stratotype on the northern part of Mesa Gigante (Moench and Puffett, 1963a, b; Moench and Schlee, 1967, pl. 3) and is not present south of there. Moench and Schlee (1967, pl. 3) showed that the Jackpile extends northwest into the subsurface only 2–3 mi (3–5 km), and Adams and Saucier (1981) showed that it extends only 6 mi (10 km) northwest from the vicinity of the stratotype.

The extent of the Jackpile north of the stratotype is a subject of some disagreement, although most recent authors agree that it extends north 50–70 mi (80–110 km) to approximately latitude 36° N. near Cuba, New Mexico (Fig. 9). Woodward and Schumacher (1973) traced it north to latitude 36°2′. Flesch (1974) mapped the Jackpile north to 35°7′30″ and was confident that it extended at least north of 35°45′ (Flesch, personal communication 1975). Saucier (1974) extended the Jackpile north to approximately 35°45′. Lupe (1983) correlated the Jackpile in the subsurface near the outcrop north to approximately 35°50′. Santos (1975) mapped the Jackpile north to approximately 36°; Owen and Siemers (1977) gave evidence that the Jackpile extends to approximately 36°.

The problem in defining the northern extent of the Jackpile lies in distinguishing between the Jackpile Sandstone and the Burro Canyon Formation. These two units are of similar lithology and identical stratigraphic position between the Brushy Basin Member of the Morrison Formation and the Dakota Sandstone along the Nacimiento front near Cuba. Owen and Siemers (1977, p. 180) ☞

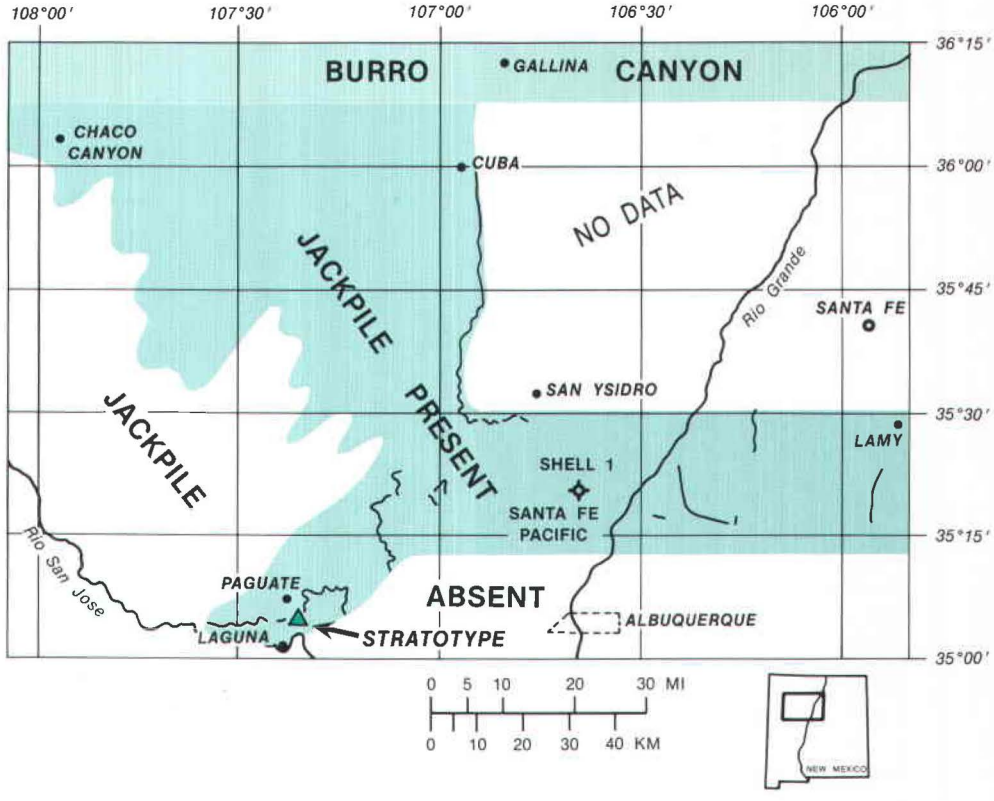


FIGURE 9—Map of approximate distribution of Jackpile Sandstone in west-central New Mexico. The Jackpile probably was deposited in the "no data" area in the eastern part of the study area, but has been removed by erosion on uplifts or covered by thick Rio Grande graben fill. The boundary on the south is due mostly to tilting and erosion along the basal Dakota unconformity. The subsurface distribution west of the outcrops is from Adams and Saucier (1981, pl. 3). The approximate southern limit of the Burro Canyon Formation is shown diagrammatically along the northern edge of the map.

pointed out that the only noticeable differences between the Burro Canyon and the Jackpile along the eastern flank of the San Juan Basin are: 1) the Burro Canyon has an unconformable basal contact, whereas the Jackpile has a conformable, but locally scoured, basal contact; 2) the Burro Canyon is generally a conglomeratic sandstone, whereas the Jackpile is generally free of conglomeratic sandstone except for a few pebbles near the base. Based on these criteria, we conclude that the Jackpile extends north to the excellent exposure at lat. 35°59′20″ N. in the roadcut between the Nacimiento open-pit copper mine and tailings pond in SW¼ NE¼ SE¼ sec. 2, T. 20 N., R. 1 W., 3.8 mi (6.1 km) southeast of Cuba. Exposures north of this locality are rare for about 17 mi (27 km) and so poor that a clear Burro Canyon–Jackpile distinction could not be made. However, the next series of well-exposed outcrops near Gallina (Fig. 9) from about 36°15′ north clearly shows Burro Canyon characteristics.

The Jackpile Sandstone can be recognized in some wells near the outcrop west of the Nacimiento front, but we have not studied to any great extent its distribution in the subsurface of the San Juan Basin. However, Adams and Saucier (1981, pl. 3) have mapped the subsurface Jackpile along a northwest trending zone from the outcrop to near Chaco Canyon (Fig. 9). Saucier (personal communication 1984) reported good control for the Jackpile mapped north to about lat. 35°40′ N., but less control for the area northwest to Chaco Canyon. The sandstone cored in the Department of Energy holes near Chaco Canyon may be from the Burro Canyon Formation. Lupe (1983) was rather conservative when he correlated the Jackpile from the outcrop into the subsurface. It appears that the Jackpile can be correlated several miles farther west and north on many of his well logs.

The Jackpile can be mapped easily to the points where it enters the subsurface in the Rio Grande graben 20–25 mi (32–40 km) northeast of the stratotype. It is present in some wells in the graben area. For example, the Jackpile can be recognized on the electric log of the Shell No. 1 Santa Fe Pacific well 43 mi (69 km) northeast of the stratotype (Fig. 9) at depths from 6812 to 6907 ft (2076–2105 m). A core across the Jackpile–Dakota unconformity allows identification of this contact. Lupe (1983) picked this contact 22 ft (7 m) high in this well by including the Oak Canyon basal sandstone in the Jackpile. East of the Rio Grande, the Jackpile is present at nearly all the isolated outcrops as far northeast as Lamy, New Mexico (Fig. 9), 14 mi (23 km) south of Santa Fe and 87 mi (140 km) northeast of the stratotype. This distribution east of the Rio Grande has not been well known, but was recently pointed out by Owen (1982, p. 268).

Thickness

At the stratotype, the Jackpile Sandstone is 100 ft (30 m) thick; in the subsurface reference section 0.8 mi (1.3 km) to the northeast, it is 125 ft (38 m) thick. The Jackpile varies considerably in thickness in the vicinity of the stratotype. The stratotype is located on the west flank of a syncline mapped by Moench and Schlee (1967, pl. 3) in which the Jackpile varies in thickness from 90 to 120 ft (27–37 m) due to slight discordance in structure between the Jackpile and Dakota. At another section, measured on the south face of South Oak Canyon Mesa, 0.7 mi (1.1 km) south of the stratotype (**LE** on Fig. 1), the Jackpile is only 52 ft (16 m) thick.

Regionally, the Jackpile also varies considerably in thickness. The Jackpile attains its maximum thickness and greatest average thickness northeast of the stratotype in an east–northeast-trending, thick belt that is 13 by 33 mi (21 by 53 km; Moench and Schlee, 1967, pl. 3). It reaches 200 ft (61 m) in thickness at several places in this belt, but thickens locally to the extreme of 300 ft (91 m; Kozusko and Saucier, 1980). Santos (1975, pl. 2) showed that most of the Jackpile is between 60 and 120 ft (18 and 37 m) thick and that it wedges out locally. Farther north, the Jackpile averages about 60 ft (18 m) in thickness, but it varies locally in the outcrops between about lat. 35°30′ and 35°40′ N. (Fig. 9). The Jackpile is thicker, generally about 130 ft (40 m), but locally variable from 35°40′ to its northern extent near 36° (Fig. 9). Santos (1975, pl. 1) mapped one outcrop approximately 0.7 mi (1.1 km) long where the Jackpile wedged out in this area. At the isolated outcrops east of the Rio Grande, the Jackpile varies considerably in thickness, even in short distances. Measured thicknesses there range from about 50 to 110 ft (15–33.5 m).

Sedimentary structures

Crossbedding is the dominant sedimentary structure in Jackpile sandstones (Fig. 10).

FIGURE 10—Easterly dipping crossbedding in lower part of Jackpile Sandstone at stratotype. Note the thinner, plane-bed zone in the middle part. Large holes in sandstone are molds formed by weathering out of mudstone clasts.

About 90% of Jackpile sandstones are crossbedded; most of the remainder are flat-bedded and a few are massive. The typical crossbed is a medium-scale wedge set with internal, planar cross-laminations. Tabular-sets, trough-sets, and concave-up cross-laminations are less common. Thickness of sets averages about one foot (0.3 m), but ranges from one inch to several feet. Regionally, the average dip direction of the crossbedding is easterly, but local and bed-to-bed variations do occur. At the stratotype, 32 measurements of crossbedding (Fig. 9) distributed throughout the Jackpile yielded a northeasterly mean dip direction of 53° (Fig. 11) with a vector magnitude of 52.5% and an F statistic of 2.23 (statistically significant at greater than 1%). The crossbedding would be oriented even more strongly if it were not for a scattering of five westerly dip directions in the upper part of the Jackpile. Other sedimentary structures seen in the Jackpile include rare parting lineations, ripple marks, load casts, and very rare insect burrows.

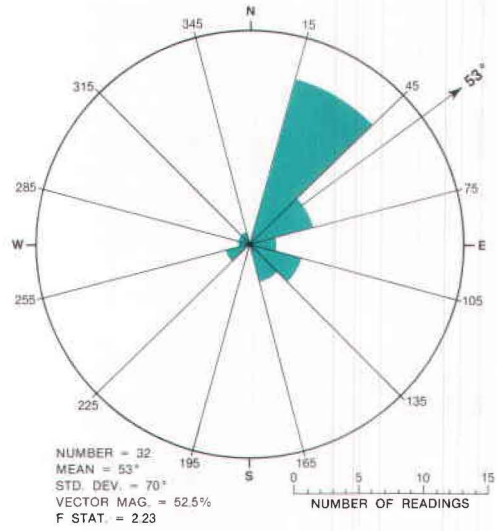


FIGURE 11—Compass rose diagram of Jackpile crossbedding directions at stratotype. The northeasterly mode and mean (53°) indicate paleocurrent-flow direction. The mean direction is statistically significant at greater than 1%. The small, southeasterly mode is not statistically significant. All five westerly readings are from the upper part of the Jackpile.

Interpretation

Age

No index fossils have been reported from the Jackpile Sandstone; therefore, no well-defined, paleontologically based age is known. The only fossils that have been discovered in the Jackpile are a few specimens of carbonaceous and petrified wood fragments and logs, insect burrows, and unidentified dinosaur bones. The stratigraphic position of the Jackpile between the rest of the Morrison Formation (reportedly Upper Jurassic) and the Dakota Sandstone (Cenomanian or lowest Upper Cretaceous) would allow it to be placed in the Upper Jurassic or Lower Cretaceous or both. Rubidium–strontium isotopic ages of very early, diagenetic barren-rock montmorillonite from nine samples of the Jackpile Sandstone at the Jackpile–Paguate mine have a mean isotopic age of 142 ± 14 Ma according to Brookins (1980, p. 54). This isotopic age was recalculated from the 146 ± 5 Ma age reported by Lee and

Brookins (1978). Such an isotopic age would give a minimum age for deposition of the Jackpile, but probably it is close to the actual age of deposition. Unfortunately, the numerical boundaries for ages of the Late Jurassic and Early Cretaceous are in considerable disagreement in the four most recently published radiometric time scales (Odin, 1982a, b; Harland et al., 1982; Palmer, 1983; van Hinte, 1976a, b). The Jurassic–Cretaceous boundary occurred 130 Ma according to Odin (1982a, b), 135 Ma according to van Hinte (1976a, b), and 144 Ma according to Harland et al. (1982) and Palmer (1983). An age of 142 Ma would have occurred sometime during the Late Jurassic Epoch according to almost all recently published time scales except the ones of Harland et al. (1982) and Palmer (1983), where it just barely falls within the Early Cretaceous (by only 2 m.y.). On Odin's scale (1982a, b) 142 Ma occurred during the Oxfordian Age of the Late Jurassic.

Until much closer agreement is reached on numerical calibration of Late Jurassic and Early Cretaceous age boundaries, we can only conclude that the Jackpile Sandstone probably was deposited during the Late Jurassic because Brookins' dates (1980) are minimum dates of deposition. Yet there still remains a slight possibility that it could have been deposited during the Early Cretaceous.

Brookins (1980) also reported that the rubidium–strontium isotopic age for Jackpile clays contemporaneous with uranium mineralization was 113 ± 7 Ma and that the age for very early diagenetic clays from the Dakota was 93 ± 8 Ma. These data indicate that the hiatus associated with the Jackpile–Dakota unconformity might be on the order of 40 m.y. (approximately all of Early Cretaceous time) and that uranium mineralization occurred during the middle of this hiatus. The 93 Ma minimum isotopic age for the Dakota agrees closely with its paleontologically determined Cenomanian age and with all of the time scales cited above.

Correlation

Significant uncertainties exist in lithostratigraphic correlation of the Jackpile Sandstone in the subsurface of the San Juan Basin and the possible confusion of the Jackpile with the Burro Canyon Formation, a Lower Cretaceous unit. For example, Swift (1956, p. 45) included all of what is now known as Jackpile and Burro Canyon from the Colorado state line to Mesa Gigante in his informal Deadmans Peak formation.

The exact age of the Jackpile is so poorly known that little can be said regarding chronostratigraphic correlation except that beds of the same age as the Jackpile may occur in the much more extensive Brushy Basin Member where the Jackpile was not developed.

Genesis

There is broad agreement among many authors who have discussed the provenance and depositional setting of the Jackpile Sandstone that it is dominantly a braided-stream deposit derived from a source area to the southwest and deposited in a fairly arid climate. Recently, Bell (1981) found evidence of tuffs that were altered in an arid climate and closed-basin evaporite minerals in the associated Brushy Basin Member including the area where the Jackpile Sandstone is present. In order to account for the logs deposited in the Jackpile, the source area of Jackpile sediments may have been somewhat less arid than at the depositional site. However, after Jackpile deposition and before Dakota deposition, there was a period of intense weathering in a humid climate that produced the weathered feldspars and white kaolinite in the Jackpile (Adams and Saucier, 1981, pp. 33–34).

In our view, the Jackpile was deposited by low to moderate sinuosity, easterly flowing, sandy braided-stream systems and on the distal portion of low-gradient alluvial-fan complexes. Migrating sand bars of various shapes in shallow water under low to moderate flow velocities in the lower flow regime formed the abundant crossbedding in the sandstones. The considerably less abundant, flat-bedded sandstones may have been formed during periods of higher flow velocity which produced upper flow regime planebed conditions. Paleocurrent data derived from the abundant crossbeds indicate a mean easterly paleoflow direction, although local variations occurred. The thin lenses of mudstone were deposited mostly in temporarily abandoned braid channels; many of the deposits were later ripped up to form mudstone clasts when the channel was reoccupied. The less common, thick lenses and beds of mudstone may represent local overbank deposits.

The thickest part of the Jackpile was deposited in a contemporaneously subsiding, structural depression according to Schlee and Moench (1961). Other fan complexes were developed near Cuba and Lamy (Fig. 9), but they are generally thinner. Local areas where the Jackpile is absent within its area of distribution may represent small interfluvial areas between braided-stream systems.

The proximal part of the alluvial-fan complex south and west of the stratotype has been removed by truncation along the basal Dakota unconformity. Therefore, the distance to the source area is conjectural. Moench and Schlee (1967, p. 21) suggested that the source of the Jackpile was a rejuvenated area south of Gallup, New Mexico, that was also the source area of other Morrison sandstone members. In this case the Jackpile would be a more easterly alluvial-fan complex similar to, but smaller than, the alluvial-fan complexes in the Salt Wash, Recapture, and Westwater Canyon Members as mapped by Craig et al. (1955) and discussed by Saucier (1976) and Galloway (1979). The Mogollon Highlands of southwest New Mexico and southeast and central Arizona also may have contributed detritus derived from basement rocks that mixed with the closer sedimentary source areas to form the Jackpile and other Morrison alluvial-fan complexes.

Conclusions

The Jackpile Sandstone Member is named here formally as the uppermost member of the Morrison Formation (Upper Jurassic) from a stratotype exposed near the Jackpile–Paguate uranium mine in Cibola County, west-central New Mexico. The stratigraphic name, Jackpile, has been used informally for this unit by numerous authors for many years.

The Jackpile is typically a whitish, medium- to coarse-grained, crossbedded, subarkosic sandstone with clay matrix and interbedded, variegated, pale-green to red, bentonitic mudstone lenses. At the stratotype the sandstone averages 58% quartz and chert, 16% feldspars, 5% rock fragments, and 21% clay matrix.

The lower contact of the Jackpile with the Brushy Basin Member of the Morrison Formation is gradational through a few inches, locally scoured, and interbedded at a few localities. The upper contact with the Dakota Sandstone is an unconformity.

The Jackpile extends only about 10 mi (16 km) southwest and 8 mi (13 km) southeast of the stratotype due to truncation along the basal Dakota unconformity, but it also extends northeast across the Rio Grande to Lamy, New Mexico, 87 mi (140 km) from the stratotype. It appears to extend north about 65 mi (105 km) to just south of Cuba, New Mexico. The Jackpile has been mapped northwest into the subsurface of the San Juan Basin to near Chaco Canyon by Adams and Saucier (1981, pl. 3).

The thickness of the Jackpile increases to the northeast from 100 ft (30 m) at the stratotype to 200 ft (61 m) or more in a contemporaneously subsiding depression. Farther north, it thins to approximately 60 ft (18 m) in the outcrops near San Ysidro, New Mexico, but thickens to approximately 130 ft (40 m) along the Nacimiento front south of Cuba, New Mexico. The Jackpile wedges out in several places and varies in thickness east of the Rio Grande.

Regionally, the crossbedding of the Jackpile indicates an easterly paleocurrent direction, but at the stratotype the direction is more northeasterly (56°). The Jackpile was deposited by braided-stream systems and on the distal portions of alluvial-fan complexes in a fairly arid climate. Source areas were a rejuvenated upland south of Gallup, New Mexico, and the distant Mogollon Highlands.

References

Adams, S. S., and Saucier, A. E., 1981, Geology and recognition criteria for uraniferous humate deposits, Grants uranium region, New Mexico: U.S Department of Energy, National Uranium Resource Evaluation GJBX-2(81), 226 pp.

Bell, T. E., 1981, A Jurassic closed basin in the Morrison Formation (abs.): Geological Society of America, Abstracts with Programs, v. 13, no. 7, p. 406.

Brookins, D. G., 1980, Geochronologic studies in the Grants mineral belt; *in* Rautman, C. A. (compiler), Geology and mineral technology of the Grants uranium region 1979: New Mexico Bureau of Mines and Mineral Resources, Memoir 38, pp. 52–58. ☞

Craig, L. C., Holmes, C. N., Cadigan, R. A., Freeman, V. L., Mullens, T. E., and Weir, G. W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region—a preliminary report: U.S. Geological Survey, Bulletin 1009-E, pp. 125–168.

Flesch, G. A., 1974, Stratigraphy and sedimentology of the Morrison Formation (Jurassic), Ojito Spring quadrangle, Sandoval County, New Mexico—a preliminary discussion: New Mexico Geological Society, Guidebook to 25th Field Conference, pp. 185–195.

———, 1975, Stratigraphy, sedimentology, and environments of deposition of the Morrison (Upper Jurassic) Formation, Ojito Spring quadrangle, Sandoval County, New Mexico: Unpublished M.S. thesis, University of New Mexico, 106 pp.

Freeman, V. L., and Hilpert, L. S., 1956, Stratigraphy of the Morrison Formation in part of northwestern New Mexico: U.S. Geological Survey, Bulletin 1030-J, pp. 309–334.

Galloway, W. E., 1979, Morrison Formation of the Colorado Plateau; *in* Galloway, W. E., et al. (eds.), Depositional and ground-water flow systems in the exploration for uranium: University of Texas (Austin), Bureau of Economic Geology, pp. 214–228.

Harland, W. B., Cox, A. V., Llewellyn, P. G., Pickton, C. A. G., Smith, A. G., and Walters, R., 1982, A geologic time scale: Cambridge, U.K., Cambridge University Press, 131 pp.

Kozusko, R. G., and Saucier, A. E., 1980, The Bernabe Montaño uranium deposit, Sandoval County; *in* Rautman, C. A. (compiler), Geology and mineral technology of the Grants uranium region 1979: New Mexico Bureau of Mines and Mineral Resources, Memoir 38, pp. 262–268.

Lee, M. J., and Brookins, D. G., 1978, Rubidium–strontium minimum ages of sedimentation, uranium mineralization, and provenance, Morrison Formation (Upper Jurassic), Grants mineral belt, New Mexico: American Association of Petroleum Geologists, Bulletin, v. 62, no. 9, pp. 1673–1683.

Lupe, Robert, 1983, Stratigraphic sections of subsurface Jurassic rocks in the San Juan Basin, New Mexico, Colorado, Utah, and Arizona: U.S. Geological Survey, Oil and Gas Investigations Chart 118, 2 sheets.

Maxwell, C. H., 1982, Mesozoic stratigraphy of the Laguna–Grants region: New Mexico Geological Society, Guidebook to 33rd Field Conference, pp. 261–266.

McBride, E. F., 1963, A classification of common sandstones: Journal of Sedimentary Petrology, v. 33, pp. 664–669.

McLemore, V. T., 1982, Uranium in the Albuquerque area, New Mexico: New Mexico Geological Society, Guidebook to 33rd Field Conference, pp. 305–311.

Moench, R. H., 1963, Geologic map of the Laguna quadrangle, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 208, 1 sheet.

Moench, R. H., and Puffett, W. P., 1963a, Geologic map of the Mesa Gigante quadrangle, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 212, 1 sheet.

———, 1963b, Geologic map of the Arch Mesa quadrangle, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 211, 1 sheet.

Moench, R. H., and Schlee, J. S., 1967, Geology and uranium deposits of the Laguna district, New Mexico: U.S. Geological Survey, Professional Paper 519, 117 pp.

Nash, J. T., 1968, Uranium deposits in the Jackpile sandstone, New Mexico: Economic Geology, v. 63, pp. 737–750.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists, Bulletin, v. 67, no. 5, pp. 841–875.

Odin, G. S. (ed.), 1982a, Numerical dating in stratigraphy: New York, John Wiley and Sons, 1040 pp.

Odin, G. S., 1982b, The Phanerozoic time scale revisited: Episodes, v. 1982, pp. 3–9.

Owen, D. E., 1982, Correlation and paleoenvironments of the Jackpile sandstone (Upper Jurassic) and intertongued Dakota Sandstone–Lower Mancos Shale (Upper Cretaceous) in west-central New Mexico: New Mexico Geological Society, Guidebook to 33rd Field Conference, pp. 267–270.

Owen, D. E., and Siemers, C. T., 1977, Lithologic correlation of the Dakota Sandstone and adjacent units along the eastern flank of the San Juan Basin, New Mexico: New Mexico Geological Society, Guidebook to 28th Field Conference, pp. 179–183.

Palmer, A. R., 1983, The decade of North American geology, 1983 geologic time scale: Geological Society of America, Geology, v. 11, pp. 503–504.

Santos, E. S., 1975, Lithology and uranium potential of Jurassic formations in the San Ysidro–Cuba and Majors Ranch areas, northwestern New Mexico: U.S. Geological Survey, Bulletin 1329, 22 pp.

Saucier, A. E., 1974, Stratigraphy and uranium potential of the Burro Canyon Formation in the southern Chama Basin, New Mexico: New Mexico Geological Society, Guidebook to 25th Field Conference, pp. 211–217.

———, 1976, Tectonic influence on uraniferous trends in the Late Jurassic Morrison Formation: New Mexico Geological Society, Special Publication no. 6, pp. 151–157.

Schlee, J. S., and Moench, R. H., 1961, Properties and genesis of "Jackpile" sandstone, Laguna, New Mexico; *in* Peterson, J. A., and Osmond, J. C. (eds.), Geometry of sandstone bodies: American Association of Petroleum Geologists, pp. 134–150.

———, 1963a, Geologic map of the Moquino quadrangle, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 209, 1 sheet.

———, 1963b, Geologic map of the Mesita quadrangle, New Mexico: U.S. Geological Survey, Geologic Quadrangle Map 210, 1 sheet.

Siemers, C. T., King, N. R., and Mannhard, G. W., 1975, Upper Jurassic and Upper Cretaceous stratigraphy and sedimentology—eastern San Juan Basin, New Mexico; *in* Field trips to central New Mexico—Rocky Mountain Section: American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, pp. 1–98.

Swift, E. R., 1956, Study of the Morrison Formation and related strata, north-central New Mexico: Unpublished M.S. thesis, University of New Mexico, 79 pp.

van Hinte, J. E., 1976a, A Jurassic time scale: American Association of Petroleum Geologists, Bulletin, v. 60, no. 4, pp. 489–497.

———, 1976b, A Cretaceous time scale: American Association of Petroleum Geologists, Bulletin, v. 60, no. 4, pp. 498–516.

Woodward, L. A., and Schumacher, O. L., 1973, Morrison Formation of southeastern San Juan Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 129, 8 pp. □

Wyoming Geological Association

Fall field conference and symposium

The Wyoming Geological Association will hold its annual field conference and symposium entitled *The Permian and Pennsylvanian geology of Wyoming* September 23–26, 1984, at the Hilton Inn, Casper, Wyoming. The tentative schedule is: Bighorns field trip and evening icebreaker on Sunday, September 23; symposium on Monday, September 24; and Hartville Uplift and Black Hills field trip (overnight in Newcastle, Wyoming) on Tuesday and Wednesday, September 25–26. Some of the subjects to be discussed at the symposium are the Goose Egg salts and the Tensleep, Casper, Leo, and Minnelusa Formations. For further information contact Paul Trump, % Mitchell Energy Corp., 1670 Broadway, Suite 3200, Denver, CO 80202 (303–861–2226) or Alec Steele, % Marathon Oil Co., P.O. Box 2659, Casper, WY 82602 (307–577–1555).

MINING REGISTRATIONS
(OCTOBER 25, 1983 THROUGH APRIL 16, 1984)

State Mine Inspector 2340 Menaul N.E. Albuquerque, NM 87107

Date and operation	Operators and owners	Location
10–25–83 clay	Operator—Garrett Mine, D'Appolonia Consulting Engineers, 2340 Alamo SE, Suite 306, Albuquerque, NM 87106; Gen. Mgr.—Dr. A. K. Kuhn, same address, phone: 842–0835; Person in charge—Bruce W. Hassinger, same address and phone; Gen. Supt.—Jerry Farris, P.O. Box 687, Grants, NM 87020; Property owner—Frank J. Burke, P.O. Box 278, Gallup, NM 87301	McKinley Co.; sec. 22, T. 15 N., R. 18 W.; Gallup mining district; private land; drift–abandoned; no material to be mined; existing adits to be opened in order to investigate subsidence problems; directions to mine: immediately east of NM–32, 0.5 mi south of the intersection of NM–32 and NM–40 in Gallup, NM
10–25–83 mill	Operator—Ambrosia Lake Mill, Quivera Mining Co., P.O. Box 218, Grants, NM 87020; Supt.—Charley Stanley, same address; Gen. Mgr.—Arthur Gebeau, same address; Other officials—Rob Luke, Rod Tregembo, Billy Stevens, Kerr–McGee Center, Oklahoma City, OK 73125	McKinley Co.; sec. 31, T. 14 N., R. 9 W.; Grants mining district; private land; ores milled—uranium; custom milling; capacity of mill—7,000 tons per day; directions to mill: approximately 21 mi north of Grants, NM on NM–509 spur
12–20–83 gold, silver	Operator—U.S. Treasury, St. Cloud Mining Co., P.O. Box 1670, Truth or Consequences, NM 87901, phone: 744–5215; Gen. Mgr.—P. S. Freeman, 1006 Kopra St., Truth or Consequences, NM, 87901, phone: 894–7739; Gen. Supt.—James Ray Nations, General Delivery, Winston, NM, phone: 894–7495; Other official—Walter Palass, Admin. Mgr., Box 1670, Truth or Consequences, NM 87901; Property owner—The Goldfield Corp., P. O. Box 1899, Melbourne, FL 32901	Sierra Co.; sec. 25, T. 11 S., R. 9 W.; private land; directions to mine: 12 mi SW of Winston, NM, past St. Cloud mill, follow signs
12–20–83 mill	Operator—St. Cloud Mill, The St. Cloud Mining Co., P.O. Box 1670, Truth or Consequences, NM 87901, phone: (505) 744–5215; Supt.—John Gilson, same address and phone; Gen. Mgr.—Patrick Freeman, same address and phone; Other official—Walter Palass, Admin. Mgr., same address and phone; Property owner—The Goldfield Corp., P.O. Box 1899, Melbourne, FL 32901	Sierra Co.; sec. 4, T. 12 S., R. 8 W.; Chloride mining district; private land; ore milled—copper, silver, and gold; capacity of mill—400 tons per day; directions to mill: 10 mi SW of Winston
1–18–84 silver	Operator—Black Silver Venture, Gold–Silver Exploration, Inc., 631 Broadway, Truth or Consequences, NM 87901; Gen. Mgr.—Dan Medley, 631 Broadway, phone: 894–2121; Person in charge—Arthur Misquez, 1315 Caballo Rd., Truth or Consequences, NM 87901, phone: 894–3943; Gen. Supt.—A. D. Richins, P.O. Box 155, Hillsboro, NM 88042, phone: 895–5694; Property owner—Black Silver Venture, 631 Broadway, Truth or Consequences, NM 87901	Sierra Co.; sec. 13, T. 15 S., R. 9 W.; Kingston mining district; federal land; directions to mine: turn north on forest road 157 halfway between Hillsboro and Kingston, go 9.5 mi to mine

continued on page 55

350002806

HYDROLOGY AND WATER-QUALITY MONITORING CONSIDERATIONS, JACKPILE URANIUM MINE, NORTHWESTERN NEW MEXICO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4226

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

HYDROLOGY AND WATER-QUALITY MONITORING CONSIDERATIONS, JACKPILE URANIUM MINE, NORTHWESTERN NEW MEXICO

By Harold H. Zehner

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4226

Prepared in cooperation with the

U.S. BUREAU OF LAND MANAGEMENT

Albuquerque, New Mexico

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Water Resources Division
505 Marquette NW, Room 720
Albuquerque, New Mexico 87102

Copies of this report can
be purchased from:

Open-File Services Section
Branch of Distribution
U.S. Geological Survey, MS 306
Box 25425, Denver Federal Center
Denver, Colorado 80225
(303) 236-7476

CONTENTS

ILLUSTRATIONS

PLATE
(In pocket)

TABLES

TABLES - Continued

TABLES - Concluded

CONVERSION FACTORS

In this report, measurements are given in inch-pound units only. The following table contains factors for converting to metric units.

Multiply units	By	To obtain units
acre-foot	1233	cubic meter
acre-foot per year	0.001233	cubic hectometer per year
cubic foot per second-day	2447	cubic meter
acre-foot per year per square mile	476	cubic meter per year per square kilometer
inch	2.540	centimeter
inch per year	25.40	millimeter per year
foot	0.3048	meter
square foot	0.09290	square meter
mile	1.609	kilometer
square mile	2.590	square kilometer
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
gallon	3.785	liter
gallon per minute	0.06309	liter per second
pound	0.4536	kilogram
acre	4047	square meter
ton (short)	0.9072	megagram or metric ton
foot per mile	0.1894	meter per kilometer

Temperature in degrees Fahrenheit (^{o}F) is converted to temperature in degrees Celsius (^{o}C) by $^{o}C = 5/9\ (^{o}F-32)$

HYDROLOGY AND WATER-QUALITY MONITORING CONSIDERATIONS, JACKPILE URANIUM MINE, NORTHWESTERN NEW MEXICO

By Harold H. Zehner

ABSTRACT

The Jackpile uranium mine, which is on the Pueblo of Laguna in northwestern New Mexico, was operated from 1953 to 1980. The abandoned mine consists of underground workings, and the Jackpile, North Paguate, and South Paguate pits, which are 200 to 300 feet deep. The mine and facilities have affected 3,141 acres of land, and about 2,656 acres were yet to be reclaimed in late 1980. The intended use of the restored land is stock grazing. Possible oxidation by ground and surface water in the backfill to be placed in the pits and in the 32 tailings and waste piles may cause increased solution of rock minerals, including radionuclides and trace elements.

The Jackpile sandstone (economic usage), which is an upper unit in the Brushy Basin Member of the Morrison Formation of Jurassic age, is the principal bedrock aquifer in the area, as well as the ore-bearing body. It is a fine- to medium-grained, poorly to moderately well sorted sandstone that ranges in thickness from 40 to 200 feet in the area. Fractured Dakota Sandstone and Mancos Shale of Cretaceous age overlie the Jackpile sandstone and a 200-foot-thick tight mudstone unit of the Brushy Basin Member underlies the Jackpile.

The hydraulic conductivity of the Jackpile sandstone probably is about 0.3 foot per day. The small storage coefficients determined from three aquifer tests indicate that the Jackpile sandstone is a confined hydrologic system throughout much of the mine area. Other water-yielding units include the thin valley alluvium, which had a hydraulic conductivity of 23 feet per day at one test well; colluvium adjacent to the mesas; and basalt flows and pyroclastic rocks west and north of the mine. Seepage from these water-yielding units probably sustains the base flow in the Rio Paguate.

The Rio Paguate flows eastward to near the center of the Jackpile mine, then southward to the Rio San Jose near the village of Laguna. The Rio Moquino is a tributary to the Rio Paguate in the northern part of the mine area. Prior to mining, the Rio Paguate was a gaining stream. During 1977-80, it had a mean daily base flow of about 0.6 cubic foot per second near the mine's south boundary; however, the stream was losing water in its reach between the Paguate pits. Sediment from the Rio Paguate has nearly filled the Paguate Reservoir near Laguna since its construction in 1940. The sediment deposited in the reservoir due to mining is estimated to be very small.

The mean concentrations of uranium, radium-226, and other trace elements generally were less than permissible limits established in national drinking-water regulations or New Mexico State ground-water regulations. No individual surface-water samples collected upstream from the mine contained concentrations of radium-226 in excess of the permissible limits. Radium-226 concentrations in many individual samples collected from the Rio Paguate from near the mouth of the Rio Moquino to the sampling sites along the downstream reach of the Rio Paguate, however, exceeded the recommended permissible concentration of radium-226 for public drinking-water supplies. Concentrations in surface water apparently are changed by ground-water inflow near the confluence of the two streams.

Part of the backfill will become saturated after reclamation. Most discharge from the Jackpile pit backfill probably will be to the Jackpile sandstone, then to the alluvium and the Rio Paguate. Discharge from the backfill in the Paguate pits primarily will be to permeable waste rock and then to the Rio Paguate. The altitude of the water tables in the backfill of the pits will be controlled partly by the water level in the Rio Paguate. Other factors controlling the altitudes of the water tables are the recharge rate to the backfill and the hydraulic conductivities of the backfill, alluvium, Jackpile sandstone, and mudstone unit of the Brushy Basin Member.

Waste piles receive only local recharge, which generally is from precipitation that falls directly on the piles. Saturation of the piles usually is limited and of short duration. Discharge from the piles may be to the land surface or to the underlying alluvium and bedrock.

After reclamation, most of the shallow ground water probably will discharge to the natural stream channels draining the mine area. The remaining ground water probably will flow to the south and east, where erosion has removed the northwest-dipping Jackpile sandstone from the valleys.

Four additional surface-water monitoring stations could be established, and samples initially could be collected about once every 2 months and at different discharges. Constituents that probably would need to be monitored are common ions, dissolved solids, trace elements, gross alpha radioactivity, gross beta radioactivity, and uranium.

Ground-water quality may be monitored as: (1) "Limited monitoring," in which only the change in water quality is determined as the ground water flows from the mine; or (2) "thorough monitoring," in which specific sources of possible contaminants are described. As few as three wells would be needed for limited monitoring; many more wells would be needed for thorough monitoring. Initially, ground-water-quality samples probably would need to be collected initially about once every 3 months.

INTRODUCTION

The area of the Jackpile mine (fig. 1) includes about 7,500 acres of land on the Pueblo of Laguna (Anaconda Copper Co., written commun., 1980). The land was leased from the Pueblo of Laguna by the Anaconda Copper Co. More than 356 million tons of material were moved since mining began in 1953, including 22 million tons of ore from the Jackpile sandstone (economic usage) of the Brushy Basin Member of the Morrison Formation; mining ceased in 1980. The mining has affected 3,141 acres of land, of which 485 acres had been reclaimed in late 1980. All of the remaining disturbed area (2,656 acres) was yet to be reclaimed in late 1980. The reclaimed land will be used for stock grazing. The remaining disturbed area consists of 1,015 acres of open pits, 1,266 acres covered by 32 piles of waste rock, 185 acres underlain by ore stockpiles, and 190 acres of supporting facilities.

Ore was excavated by the open-pit method from 1953 to late 1980. The open-pit areas consist of the Jackpile pit (first area mined), located in the eastern part of the mine area, and the North and South Paguate pits, located in the northwest and west-central parts of the mine area. Underground mining started in 1974 and continued to late 1980. Most underground workings are located in the southwestern part of the Jackpile mine area.

The population centers nearest to the Jackpile mine are the village of Paguate, about 0.1 mile to the west, and the villages of Bibo and Moquino, 2 miles to the north. Laguna and Mesita, which are 6 to 7 miles south of the mine, are upstream and downstream, respectively, from the confluence of the Rio Paguate with the Rio San Jose (fig. 1). The nearest city is Albuquerque, located about 60 miles (by road) east of the mine.

Surface water from the Rio Paguate is used for irrigation near the village of Paguate. Upstream from Mesita, water from the Rio San Jose is used for irrigation on the Pueblos of Laguna and Acoma.

Ground water on the Pueblo of Laguna is used for public supply, livestock, and industry (F. P. Lyford, U.S. Geological Survey, written commun., 1977). Public supplies are obtained from one well near Mesita and two wells near Paguate. Most wells drilled for individual household use have been abandoned in favor of better quality water from public-supply wells.

The Jackpile uranium mine will be reclaimed by backfilling parts of 3 open pits and recontouring 32 waste piles. The reclaimed land is intended for livestock grazing. Primary hydrologic concerns are that the weathering of exposed backfill and waste rock in the disturbed areas may promote solution of undesirable chemical constituents, such as radionuclides and trace elements, that may move into surface-water or ground-water supplies.

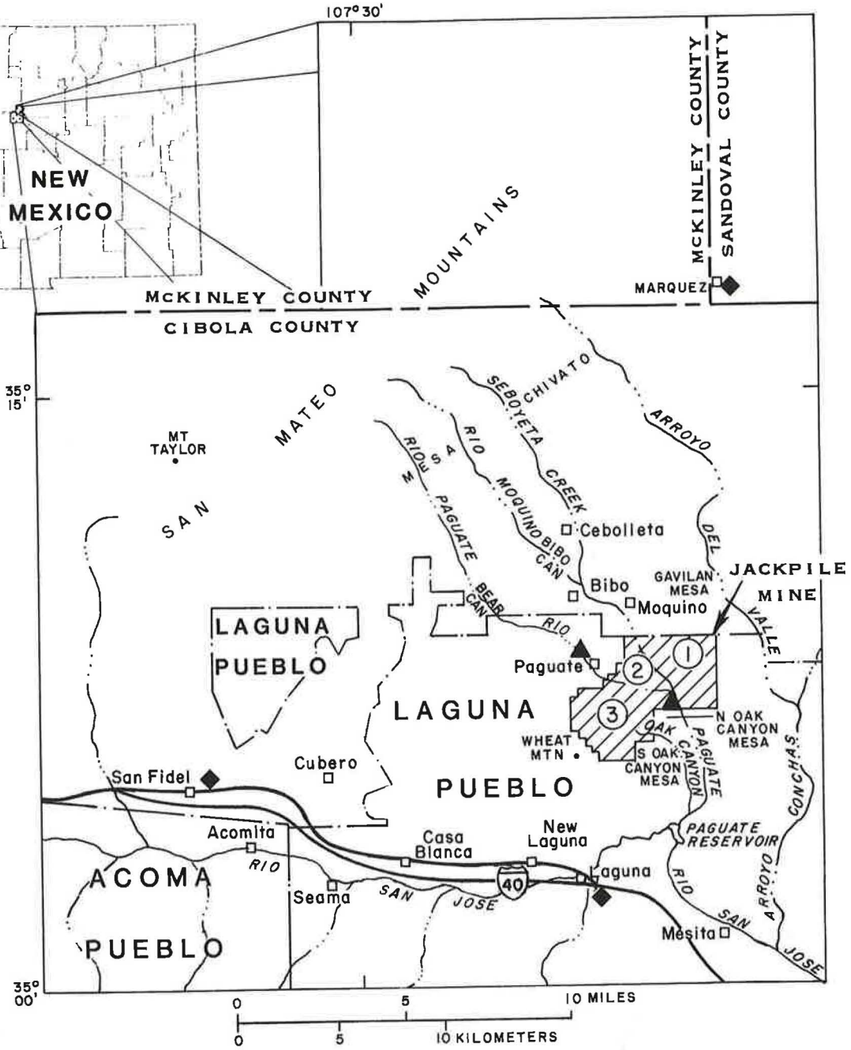


Figure 1.--Location of the Jackpile uranium mine.

Purpose and Scope

The purposes of this report are as follows:

1. To describe the 1980 hydrologic and water-quality conditions in and near the Jackpile mine that are related to the disturbed surface area of the mine.

2. To describe possible hydrologic flow conditions that might develop after reclamation of the mine and that might affect the quality of surface and ground water.

3. To present reasons for and possible methods of hydrologic monitoring that would be useful in establishing a post-reclamation ground- and surface-water quality monitoring network.

The scope of the report consists of describing the 1980 surface- and ground-water systems, including the rate and direction of flow and the water quality. Possible ground- and surface-water flow conditions after pit backfilling and considerations that may be useful in post-reclamation water-quality monitoring are discussed. Geohydrologic data collected prior to the study and reports were the primary sources of information used in the study. Data collected during the study consisted of streamflow data calculated from channel-geometry techniques; water-level measurements in holding ponds, mine pits, and 34 wells; and aquifer-test data at 5 wells.

The study was conducted during 1981-82 in cooperation with the U.S. Bureau of Land Management. The hydrologic information included in the report may be used in the preparation of an Environmental Impact Statement and the mine-reclamation plans.

Topography and Drainage

Prominent topographic features in the area of the Jackpile mine are the San Mateo Mountains and numerous mesas (fig. 2). Mount Taylor is the highest point in the area at altitude 11,300 feet and is located about 15 miles northwest of the Jackpile mine. Wheat Mountain (altitude 7,140 feet) and the drainage divides southeast of Mesa Chivato are topographically high areas that are fairly close to the mine. Within the lease boundary, altitudes range from 5,820 to 6,910 feet. The prominent features in the mine area are Gavilan Mesa at the northeast corner and North and South Oak Canyon Mesas along the southern edge. Other features include several smaller unnamed mesas and numerous piles of waste rock and stockpiled ore. The mine pits are as much as 200 to 300 feet below the adjacent land surface. The piles of waste rock are as much as 200 feet in height; most are about 50 to 75 feet high.

Drainage through the Jackpile mine is by the Rio Paguate and Rio Moquino, whose headwaters are in the San Mateo Mountains (fig. 2). The Rio Moquino becomes part of the Rio Paguate near the center of the mine. The Rio Paguate flows southeastward into Paguate Reservoir about 3 miles south of the southern mine boundary, then joins the Rio San Jose (altitude 5,700 feet) about 1 mile south of where the Rio Paguate enters the reservoir. The Rio San Jose, the main stream in the Laguna area, flows into the Rio Puerco about 25 miles southeast of its confluence with the Rio Paguate.

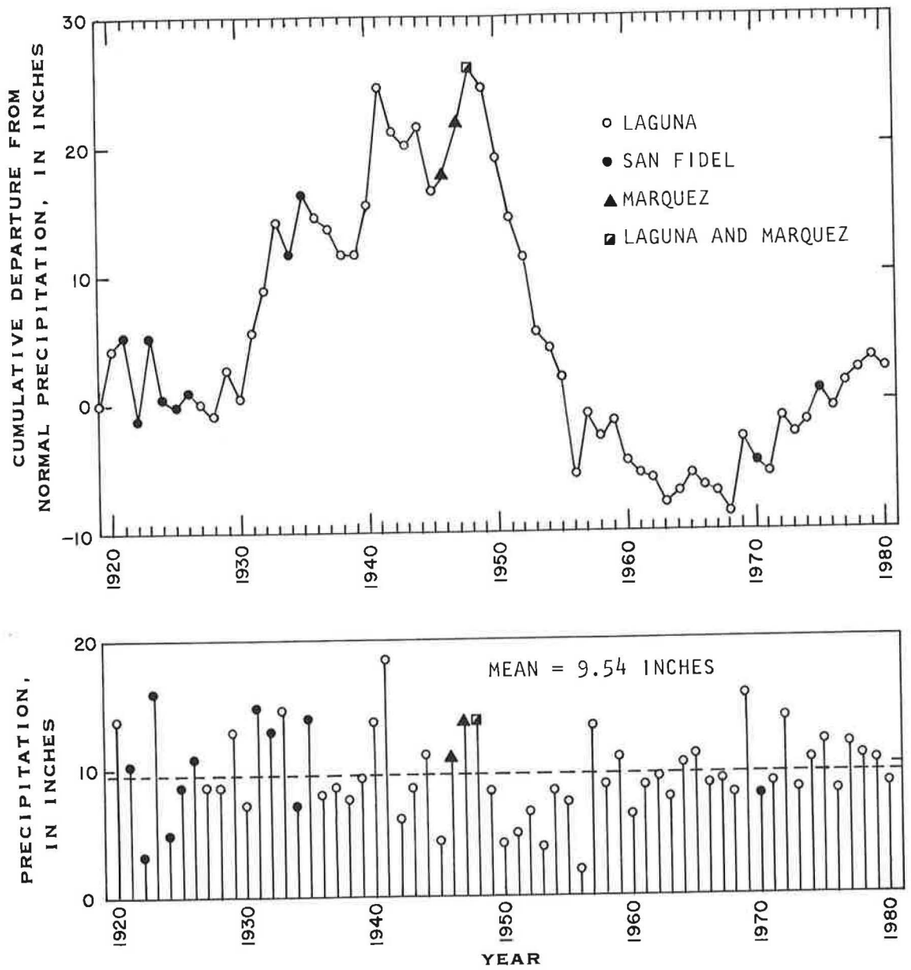


Figure 2.--Annual precipitation and cumulative departure from normal precipitation in the Laguna area.

Climate

The climate of northwestern New Mexico is characterized by minimal precipitation and significant evapotranspiration. Precipitation data were used from three stations operated by the U.S. Department of Commerce in the Laguna area. The stations (fig. 2) are located at the following towns: Laguna, about 7 miles south of the Jackpile mine at an altitude of 5,800 feet; San Fidel, about 12 miles west of Laguna at an altitude of 6,100 feet; and Marquez, about 13 miles north of the Jackpile mine at an altitude of 7,800 feet. Climatic data from a long-term station at Los Lunas also were used because several years of pan-evaporation data are available for the station. Los Lunas is located about 45 miles southeast of the Jackpile mine in the Rio Grande valley at an altitude of 4,800 feet.

Annual precipitation and years of record are shown in table 1. The annual precipitation generally is less than 15 inches, but quite variable. For example, the range for Laguna is from 1.96 inches (1956) to 18.42 inches (1941).

Mean monthly and mean annual precipitation at the four stations are presented in table 2. Only complete years of record were used in computing monthly means. About 60 percent of the precipitation occurs during the 5 months from May through September, with the greatest precipitation during July, August, and September. Mean annual precipitation is similar at Laguna and San Fidel. Precipitation at these two stations is about 15 percent greater than at Los Lunas and about 20 percent less than at Marquez.

All data from the Laguna station were used for plotting cumulative departure from mean annual precipitation after 1919 (fig. 2). Some data from other stations were used for years of incomplete record at Laguna. Mostly, data from San Fidel were used to fill in gaps of missing record, but precipitation at Los Lunas and Marquez was used for some years. The 15- to 20-percent differences between the data from Laguna and from Los Lunas-Marquez and the few years of data used from the latter stations are assumed to introduce negligible error in cumulative departure for the Laguna area. Monthly data from Laguna and Marquez were combined to obtain a total of 13.67 inches for 1948.

A 9.54-inch normal was used for 1919-80. This is considered a reasonable approximation for the Laguna area because mean annual precipitation at Laguna is 9.48 inches and the mean for all values on the cumulative departure plot is 9.54 inches. Departure from normal in 1919 is assumed to be zero (fig. 2).

Precipitation frequencies (table 3) range, on average, from 1.2 inches per 24 hours every 2 years to as much as 2.8 inches per 24 hours every 100 years.

Monthly pan evaporation at Laguna is shown in table 4, and that at Los Lunas is shown in table 5. Mean monthly pan evaporation ranged from about 0.5 to about 2 inches more during April through November at Laguna than at Los Lunas. Maximum differences are only 16 percent between monthly means, however, with differences for most months less than 8 percent. In this report, the mean annual pan evaporation at Laguna is assumed equal to that at Los Lunas, which is about 76 inches More than 60 percent of annual pan evaporation occurs during May through September. Months of greatest evaporation correspond to months of greatest precipitation.

Table 1.--Annual precipitation at four stations near the Jackpile mine

[All values are in inches. Data from New Mexico State Engineer Office (1956) and annual publications of precipitation data by the U.S. Department of Commerce]

Year	Laguna[1/]	San Fidel	Marquez	Los Lunas	Year	Laguna	San Fidel	Marquez	Los Lunas
1891	--	--	--	16.37	1936	7.88	8.90	--	5.13
1892	--	--	--	6.11	1937	8.59	7.86	--	7.72
1893	--	--	--	8.40	1938	7.55	8.53	--	4.67
1894	--	--	--	4.55	1939	9.37	12.34	--	7.70
1895	--	--	--	--	1940	13.54	14.91	--	11.08
1896	--	--	--	7.65	1941	18.42	22.64	--	--
1897	--	--	--	--	1942	6.00	6.31	10.38	--
1898	--	--	--	--	1943	8.43	9.38	15.51	--
1899	--	--	--	--	1944	11.10	--	14.55	--
1900	--	--	--	8.05	1945	4.43	--	9.69	--
1901	--	--	--	--	1946	--	--	10.85	--
1902	--	--	--	--	1947	--	--	13.46	--
1903	--	--	--	--	1948	--	--	--	--
1904	--	--	--	10.45	1949	8.14	--	13.12	--
1905	--	--	--	--	1950	4.03	--	5.22	5.23
1906	13.05	--	--	11.67	1951	4.75	5.82	8.95	4.80
1907	--	--	--	15.85	1952	6.46	8.90	12.32	6.34
1908	8.35	--	--	5.27	1953	3.73	6.36	9.64	--
1909	10.60	--	--	4.25	1954	8.21	8.72	10.95	--
1910	9.08	--	--	--	1955	7.25	6.78	9.12	7.89
1911	12.90	--	--	11.57	1956	1.96	--	5.21	2.87
1912	--	--	--	5.47	1957	13.12	10.39	19.56	8.18
1913	8.68	--	--	7.77	1958	8.72	9.27	16.05	6.25
1914	--	--	--	10.21	1959	10.74	19.07	12.70	8.74
1915	--	--	--	12.13	1960	6.28	8.49	12.27	7.71
1916	--	--	--	10.14	1961	8.53	8.61	13.08	8.26
1917	--	--	--	2.15	1962	9.19	7.85	11.73	6.36
1918	--	--	--	9.94	1963	7.63	8.10	9.12	6.34
1919	--	--	--	10.84	1964	10.30	7.72	9.45	6.34
1920	13.81	--	--	6.27	1965	10.92	--	13.14	10.17
1921	--	10.35	--	9.26	1966	8.67	7.91	7.90	5.50
1922	--	3.15	--	3.24	1967	8.86	10.16	13.37	8.93
1923	--	15.89	--	9.07	1968	7.83	7.83	7.00	8.43
1924	--	4.93	--	5.83	1969	15.44	10.16	12.67	10.31
1925	--	8.55	--	8.37	1970	--	7.70	6.56	5.90
1926	--	10.78	--	8.11	1971	8.69	7.81	7.18	7.83
1927	8.66	13.06	--	9.40	1972	13.74	13.54	11.44	13.37
1928	8.65	11.10	--	10.26	1973	8.17	7.54	8.59	10.17
1929	12.94	12.25	--	14.07	1974	10.40	10.16	8.17	11.12
1930	7.14	7.95	--	5.08	1975	11.92	8.84	--	5.99
1931	--	14.68	--	10.44	1976	7.95	--	--	5.42
1932	--	12.83	--	10.15	1977	11.57	--	--	8.18
1933	14.64	11.98	--	7.30	1978	10.65	--	--	9.75
1934	--	7.23	--	4.34	1979	10.36	--	--	8.19
1935	--	13.93	--	6.07	1980	8.66	--	--	7.53

[1/] Precipitation recorded prior to 1891: 1850 = 9.69 inches and 1851 = 15.12 inches.

Table 2.--Mean monthly and mean annual precipitation at four stations near the Jackpile mine

[All values are in inches. Data from New Mexico State Engineer Office (1956) and annual publications of precipitation data by the U.S. Department of Commerce]

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Laguna	0.36	0.47	0.43	0.39	0.60	0.60	1.74	1.73	1.40	0.92	0.34	0.50	9.48
San Fidel	.24	.37	.39	.22	.41	.36	1.45	2.12	1.29	1.29	.24	.44	9.36
Marquez	.57	.29	.50	.73	.63	.79	1.56	2.95	1.22	.81	.54	.65	11.22
Los Lunas	.35	.32	.45	.47	.58	.56	1.11	1.50	1.11	.89	.31	.42	8.06

Table 3.--Precipitation frequencies in the Jackpile mine area

[All values are in inches. Data from the U.S. Department of Commerce (1967)]

2-year, 24-hour	5-year, 24-hour	10-year, 24-hour	25-year, 24-hour	50-year, 24-hour	100-year, 24-hour	5-year, 6-hour	10-year, 6-hour	25-year, 6-hour	50-year, 6-hour	100-year, 6-hour
1.2	1.6	1.9	2.3	2.6	2.8	1.3	1.6	1.8	2.1	2.2

Table 4.--Monthly pan evaporation at Laguna

[All values are in inches. Data obtained from annual publications by the U.S. Department of Commerce]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1974	--	--	--	--	--	12.54	10.90	8.92	6.90	3.78	--	--
1975	--	--	--	--	--	13.09	10.19	9.78	--	--	--	--
1976	--	--	--	8.76	11.26	13.09	11.52	9.59	5.88	5.36	--	--
1977	--	--	--	--	10.89	11.22	10.31	9.56	6.77	5.56	--	--
1978	--	--	--	9.33	9.83	12.79	11.98	9.77	7.24	5.92	2.20	--
Mean	--	--	--	9.05	10.66	12.55	10.98	9.52	6.70	5.16	2.20	--

Table 5.--Monthly pan evaporation at Los Lunas

[All values are in inches. Sum of monthly means from all data is 75.52 inches. Data obtained from annual publications by the U.S. Department of Commerce]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1962	--	--	--	--	--	--	--	--	6.79	5.00	--	--
1963	--	--	--	10.34	10.96	11.63	11.25	9.87	7.49	4.61	--	--
1964	--	--	--	8.13	12.13	12.83	11.17	9.89	6.66	--	--	--
1965	--	--	--	8.24	10.82	10.23	10.99	9.02	7.12	4.92	--	--
1966	--	--	5.70	9.04	11.81	11.39	10.28	9.70	6.39	5.40	--	--
1967	--	--	7.02	9.64	10.47	11.00	10.41	7.88	6.36	5.90	--	--
1968	--	--	--	9.19	10.24	13.55	12.07	9.91	7.62	5.01	--	--
1969	--	--	4.00	6.22	9.07	10.77	9.30	11.29	4.91	4.87	1.81	--
1970	--	--	4.94	10.47	10.53	10.29	9.48	9.73	6.90	2.77	--	--
1971	--	--	--	8.27	8.58	11.47	12.07	9.37	7.52	3.01	--	--
1972	--	--	--	7.96	8.23	9.74	10.84	9.22	6.60	2.57	--	--
1973	--	--	2.48	3.79	8.33	10.64	9.73	9.39	6.68	4.54	--	--
1974	--	--	7.17	8.20	10.30	11.91	11.07	8.31	--	4.59	2.57	--
1975	--	--	5.64	7.89	9.09	9.53	8.40	9.15	--	5.56	--	--
1976	--	--	--	7.94	9.32	10.72	9.94	8.50	6.00	4.66	3.04	--
1977	--	2.79	5.75	6.75	9.82	10.18	9.83	9.07	5.88	4.76	3.47	.53
1978	2.00	2.99	5.11	8.99	9.01	10.38	9.90	9.96	7.45	4.71	2.09	--
Mean[1/]	2.00	2.89	5.31	8.19	9.92	11.02	10.42	9.39	6.69	4.56	2.60	2.53
Mean[2/]	--	--	--	8.47	9.38	10.54	9.83	9.00	6.44	4.86	2.09	-

[1/] All months of record, with single values assumed equal to mean.
[2/] Only months for which data also were obtained at Laguna.

Acknowledgments

Anaconda Copper Co. personnel provided access and guidance through all areas of the Jackpile mine. William Griego of Anaconda Copper Co. assisted in collecting hydraulic-head data from wells.

Several U.S. Geological Survey personnel made significant contributions to this report and are acknowledged as follows. Jack D. Dewey estimated sediment transport rates in the Rio Paguate drainage basin. Discussions with Richard F. Hadley were helpful in assessing principal factors associated with sediment deposition in reservoirs. John P. Borland estimated flood frequencies for the local streams. Herberto B. Mendieta, with assistance from Kim Ong, summarized the available chemical data and described water quality. Several persons in the Albuquerque office participated in collecting and analyzing aquifer-test data, particularly Paul A. Davis and James A. Basler.

SURFACE WATER

Streamflow data were collected on the Rio Paguate upstream from the village of Paguate (referred to as Paguate Creek near Laguna) from March 1937 through September 1941 and at the southern boundary of the Jackpile mine near Laguna from March 1976 through September 1980 (fig. 1). Discharge was not measured on the Rio Moquino.

A summary of the discharge data by water years (October through September) is shown in table 6. Mean monthly and mean annual discharge are given in Supplemental Information.

Table 6.--Summary of discharge data for Rio Paguate upstream from Paguate (water years 1938-41) and Rio Paguate at the southern boundary of the mine near Laguna (water years 1977-80)

[All values are in cubic feet per second except as indicated]

Water year	Maximum daily	Mean daily	Minimum daily	Total (cubic feet per second-days)
1938	--	0.99	0.20	[1/]361
1939	--	1.02	.40	[1/]372
1940	--	1.02	.30	[1/]372
1941	--	3.80	.40	[1/]1387
1977	34	1.48	.04	539.07
1978	42	1.08	.07	394.03
1979	14	1.33	.06	485.94
1980	42	.87	.00	316.66
Mean for 1938-41	--	1.71	.32	623
Mean for 1977-80	33	1.19	.04	433.93

[1/] Approximated by multiplying mean daily discharge by 365 days.

The mean daily discharge for water years 1938-41 at the gaging station upstream from Paguate was 1.71 cubic feet per second. The value is affected considerably by the unusually large discharge during water year 1941. Precipitation for calendar year 1941 was the greatest recorded at Laguna and caused the anomalously large discharge value. The Rio Paguate usually flows all year. It is occasionally dry at the gaging station at the southern boundary of the Jackpile mine, as shown by the minimum daily discharge in table 6. The mean daily discharge for water years 1977-80 at the southern station was 1.19 cubic feet per second.

The stream discharge is only about 2 percent of the precipitation in the Rio Paguate drainage basin, as will be discussed in the "Water Balance" section of this report. This illustrates the extremely large evapotranspiration in the area.

Base Flow

In humid areas, ground-water discharge to streams (base flow) generally is determined by computing a constant slope from the decreasing limb of the discharge plot (recession), then using this slope as a control for estimating base flow during recessions. In the arid Rio Paguate drainage basin, floods are infrequent during winter months, so that most discharge is base flow during this time. More frequent floods in summer are caused by thunderstorms that are intense, but of short duration. The recessions are, therefore, rapid. Their slopes are difficult to determine, not constant, and not completely controlled by ground-water discharge.

Ground-water gradients near the streams are reversed (hydraulic head is greater in the stream than in the adjacent aquifer) when the stream stage rises and during the early part of the recession. Base flow during this time is zero. The stream may, in fact, be losing water to bank storage. Base flow at the Rio Paguate gaging station was approximated by assuming there is no ground-water discharge during the entire rising and receding stages of the stream. The method is similar to that described by Daniel and others (1970).

Ground-water discharge during recessions was not taken into account for the Rio Paguate, so base-flow values may be too small. The error probably is not significant however, because: (1) Discharge during much of the receding stage of summer floods is low, compared to greater, predominantly base-flow periods in winter; and (2) some of the discharge during receding stages is from temporary ground-water storage very near the stream (bank storage), whereas the flow of primary interest in this study is the regional ground-water discharge to the stream.

Most base flow to the Rio Paguate occurs during winter (table 7) and constitutes a large percent of the total flow in the Rio Paguate. Base flow was 51 percent of total flow in water year 1977, 56 percent in 1978, 35 percent in 1979, and 60 percent in 1980.

Table 7.--Monthly and annual base flow in Rio Paguate below Jackpile mine near Laguna

[All values are in cubic feet per second-days]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1977	18.5	29.7	34.1	29.8	37.7	46.1	18.5	38.1	13.8	0.48	0.63	9.10	277
1978	14.1	16.3	29.3	40.0	22.4	43.1	24.1	19.4	7.50	.77	1.46	2.84	221
1979	3.84	12.3	19.5	11.1	16.0	.9.7	40.8	28.4	12.9	1.91	4.39	10.6	171
1980	8.56	16.4	17.4	26.7	31.3	55.9	23.7	5.88	3.11	.33	.08	.43	190
Mean	11.2	18.7	25.1	26.9	26.8	38.7	26.8	22.9	9.33	0.87	1.64	5.74	215

The mean of 215 cubic feet per second-day is equivalent to about 426 acre-feet per year or a continuous mean daily discharge of 0.6 cubic foot per second.

Flood Frequency

Flood frequencies were estimated at three locations near the Jackpile mine: on the Rio Paguate 500 feet upstream from the northwest mine-lease boundary; on the Rio Moquino 1,500 feet downstream from the northern mine-lease boundary; and on the Rio Paguate 400 feet upstream from the gaging station near the southern mine-lease boundary. Streamflow data from the gaging station were used to estimate flood frequency by use of the U.S. Geological Survey flood-flow-frequency program (J407). Two other methods were used for all locations: the basin-characteristics method described by Thomas and Gold (1982), and the channel-geometry method described by Scott and Kunkler (1976).

Measurements for use in the flood-frequency methods are given in table 8. Peak discharges were determined for recurrence intervals of 5, 10, 25, 50, 100, 200, and 500 years (table 9). Flood frequencies obtained by using the channel-geometry method are, on average, about three times less than those obtained using the basin-characteristics method. Those values obtained by the latter method are probably more accurate than those from the channel-geometry method because standard estimates of error are smaller for the method, and values obtained by the basin-characteristics method more closely approximate those obtained by use of streamflow data in the flood-frequency program.

Table 8.--Measurements used for estimating flood frequency in the Jackpile mine area

Location	Active channel width (feet)	Contributing drainage area (square miles)	Site altitude (feet)
Rio Paguate upstream from Jackpile mine	10	30.8	6,070
Rio Moquino upstream from Jackpile mine	12	68.6	6,000
Rio Paguate downstream from Jackpile mine	20	107	5,820

Table 9.--Flood frequencies at three locations in the Jackpile mine area

Recurrence interval (years)	Discharge by flood-frequency program (cubic feet per second)	Discharge by basin-characteristics method (cubic feet per second)	Discharge by channel-geometry method (cubic feet per second)
	Rio Paguate upstream from Jackpile mine		
5	--	762	208
10	--	1,180	337
25	--	1,890	558
50	--	2,590	774
100	--	3,370	1,000
200	--	4,260	1,300
500	--	5,780	1,800
	Rio Moquino upstream from Jackpile mine		
5	--	1,140	276
10	--	1,740	442
25	--	2,730	722
50	--	3,700	993
100	--	4,780	1,300
200	--	5,990	1,700
500	--	8,030	2,500
	Rio Paguate downstream from Jackpile mine		
5	1,810	1,520	609
10	2,710	2,310	946
25	4,150	3,610	1,490
50	5,450	4,880	2,000
100	6,940	6,290	2,600
200	8,670	7,860	3,300
500	11,300	10,500	4,400

The estimates of flood frequencies may prove useful for design of structures such as road culverts during reclamation of the Jackpile mine. Flood-prone areas could be outlined by using the flood-frequency values. The areas are partly dependent on existing structures in the mine, however, and probably would be changed considerably during reclamation of roads, culverts, and other stream constrictions such as waste piles presently in the channels.

Ponding at Waste Piles

An unnamed valley on the east side of Gavilan Mesa is blocked by waste-rock dumps C, D, E, F, and G (pl. 1). Overland runoff occasionally ponds at the base of the dumps. The ponded water may, therefore, infiltrate both the valley alluvium and the waste rock. The expected depths of water in the pond are discussed in this section.

The initial depths of ponded water after floods were computed by deriving a stage-capacity curve (fig. 3) from a topographic map, then determining discharge in the valley using the streamflow-characteristics method described by Borland (1970). The pertinent factors relating to streamflow characteristics in the unnamed valley and their corresponding values are: drainage area, 0.97 square mile; precipitation from October through April, 3 inches; longitude, 107 degrees 10 minutes; soils infiltration index, 8.5; and mean basin altitude, 6,070 feet.

Flood volumes and depths of ponded water are shown in table 10 for different recurrence intervals. Maximum depth is 3.9 feet for a flood flow of 1 day at a recurrence interval of 50 years. Depths are less than 2 feet for most flow periods and recurrence intervals.

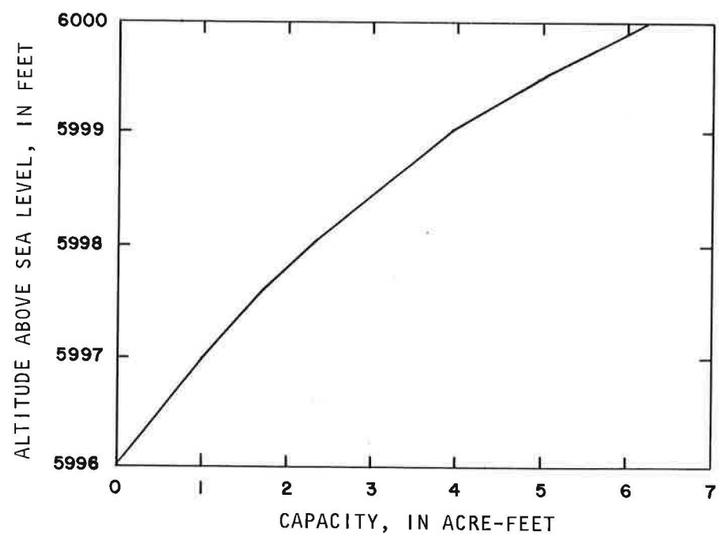


Figure 3.--Stage-capacity curve for the ponding area near waste dumps C, D, E, F, and G at the Jackpile mine.

Table 10.--Flood volumes and depths of ponded water in valley at east side of Gavilan Mesa

Floods and recurrence intervals[1/]	Volume (cubic feet per second-days)	Volume (acre-feet)	SE[2/] (percent)	Altitude of water level (feet)	Depth of water (feet)
$F_{1,2}$	0.29	0.6	59	5,996.6	0.6
$F_{1,5}$	.84	1.7	55	5,997.6	1.6
$F_{1,10}$	1.31	2.6	55	5,998.2	2.2
$F_{1,25}$	2.13	4.2	60	5,999.2	3.2
$F_{1,50}$	2.90	5.8	66	5,999.9	3.9
$F_{3,2}$	.12	.2	62	5,996.2	.2
$F_{3,5}$	.34	.7	56	5,996.7	.7
$F_{3,10}$	.54	1.1	55	5,997.1	1.1
$F_{3,25}$	.88	1.7	56	5,997.6	1.6
$F_{3,50}$	1.17	2.3	60	5,998.0	2.0
$F_{7,2}$	.06	.1	61	5,996.1	.1
$F_{7,5}$	.15	.3	58	5,996.3	.3
$F_{7,10}$	.24	.5	56	5,996.5	.5
$F_{7,25}$	.37	.7	56	5,996.7	.7
$F_{7,50}$	.48	1.0	59	5,997.0	1.0

1/ $F_{n,m}$ is flood volume for flow period n, at recurrence interval m: for example, $F_{1,2}$ means flood volume for 1 day at 2-year recurrence interval.
2/ Standard error of estimate.

Yield and Deposition of Sediment at Paguate Reservoir

Sediment has nearly filled the Paguate Reservoir (fig. 1) since construction of the dam in 1940. At present, ponding occurs only in the immediate vicinity of the dam and spillway. The Pueblo of Laguna is concerned that operation of the Jackpile mine may have increased the volume of sediment deposited in the reservoir. Three principal factors affecting reservoir sedimentation are the rate of sediment transport, the rate of sediment deposition, and the trap efficiency (proportion of sediment inflow retained by the reservoir).

Dames and Moore (written commun., 1980) used sediment volume and rates of sediment deposition, as determined from topographic maps made at different times, to evaluate the effect of the Jackpile mine on sedimentation in the Paguate Reservoir. The mean rates of deposition computed were 71 acre-feet per year from 1940 to 1949 and 22 acre-feet per year from 1949 to 1980. Based on the latter rate, the volume of sediment deposited since mining began in 1953 until 1980 is about 620 acre-feet. This is 47 percent of the total 1,333 acre-feet of sediment accumulated.

The greater rate of deposition during 1940 to 1949 was likely due to: (1) Greater sediment transport in early years due to greater than normal precipitation (fig. 2)--rainfall during 1941 was 18.42 inches, which is the greatest in all 55 years of record at Laguna (table 1); and (2) much greater trap efficiency during earlier years--efficiency would have been 100 percent during the time the reservoir was filling with water.

The rate of sediment transport, which is sediment yield, has not been measured in the Rio Paguate drainage basin. An approximate yield was computed by using a method described by Shown (1970), in which ratings are placed on several characteristics affecting yield (table 11).

Table 11.--Rating ranges of factors used for estimating sediment yields

[Modified from Shown, 1970]

Factor	Rating range	Main characteristics considered
A. Surface geology	0-10	Rock type, hardness, weathering, fracturing.
B. Soils	0-10	Texture, aggregation, salinity, caliche.
C. Climate	0-10	Storm frequency, intensity, duration.
D. Runoff	0-10	Volume per unit area, peak flow per unit area.
E. Topography	0-20	Steepness of upland slopes, relief.
F. Ground cover	-10-10	Vegetation, litter, rocks.
G. Land use	-10-10	Percentage cultivated, grazing intensity, logging, roads.
H. Upland erosion	0-25	Rills and gullies, landslides.
I. Channel erosion and sediment transport	0-25	Bank and bed erosion, flow depths, active headcuts, channel vegetation.

Ratings were made for the entire Rio Paguate drainage basin; the Jackpile mine before mining; and the Jackpile mine in its present (1980) condition (table 12). Drainage is into closed basins (pits) for 5.0 square miles of the 6.0 square miles in the mine area. The ratings for the present (1980) conditions apply to the 1.0 square mile with external drainage.

Shown (1970) described the correspondence of ratings and estimated sediment yields, in acre-feet per year per square mile, as follows: a rating of 25 to 50 gives a yield of 0.2 to 0.5, and a rating of 100 to 125 gives a yield of 3.0 to 7.0. Ratings in table 12 were summed for each drainage area and the corresponding yield computed (table 13). The net sediment yield due to mining operations was estimated as the difference between before and after mining, which is 3.5 - 3.0 = 0.5 acre-foot per year. The estimated present (1980) rate of sediment yield due to mining is only about 1.0 percent of the 46 acre-feet per year total yield in the basin. This percentage may be too large if used to compute total yield since mining started because a smaller mined area was exposed during the early years of operation.

Table 12.--Descriptions of characteristics and ratings for estimating sediment yield in the Rio Paguate drainage basin

Factor*	Rating	Description
		Total Rio Paguate drainage basin upstream from the mine
A	5	Rocks are of medium hardness, moderately weathered, and fractured.
B	5	Soils are medium textured with occasional rock fragments.
C	8	Most runoff is due to intense convective storms, but runoff has small volume.
D	5	Runoff occurs as high peaks, but has small volume.
E	12	The average upland slopes are less than 30 percent, but there is little flood plain.
F	-5	Upper areas have good ground cover and the lower areas have moderate ground cover.
G	-10	Little cultivation, recent logging, and grazing.
H	5	Signs of erosion on less than 25 percent of the land surface.
I	15	Active headcuts and degradation in tributary channels, but flow duration is short.
		Jackpile mine area before beginning mining operations
A thru E		Same as described above.
F	0	Lower areas have moderate ground cover.
G and H		Same as described above.
I	20	Headcuts and degradation are more prevalent in downstream reaches.
		Jackpile mine area in present (1980) condition
A thru D		Same as described above.
E	20	External drainage is mostly from the steep slip faces on the outsides of the waste piles.
F	10	Very little ground cover.
G	10	Land use extensive.
H	25	Rills cover about 50 percent of the land surface.
I	15	Much of the sediment eroded from the slip faces is deposited at the bottoms of the faces.

*Corresponds to factors in table 11.

Table 13.--Estimates of sediment yield in the Rio Paguate drainage basin

Drainage area description	Rating total	Unit yield (acre-feet per year per square mile)	Area (per square mile)	Total yield (acre-feet per year)
Entire Rio Paguate drainage basin	40	0.38	120	46.0
Mine area before mining began	50	.50	6.0	3.0
Mine area at present (1980)	103	3.5	1.0	3.5

Only part of the approximate 0.5 acre-foot per year yield was actually deposited in Paguate Reservoir because trap efficiency was less than 100 percent during mining. Using the deposition rate of 22 acre-feet per year for 1949 to 1980, as determined by Dames and Moore (written commun., 1980), and the total yield in the Paguate drainage basin, the trap efficiency would be about 48 percent (22 acre-feet per year divided by 46 acre-feet per year). Using the 0.5 acre-foot per year (maximum) yield during mining, the mean sedimentation rate during mining would have been less than 0.24 acre-foot per year (0.5 acre-foot per year x 0.48).

Trap efficiency probably would apply equally to both mine sediment and total basin sediment, so the proportion of sediment deposited from mining to that deposited from total basin erosion is the same as the proportion for sediment yield, which is about 1.0 percent. The small percentage results from the fact that the mine area constitutes a small part of the total Rio Paguate drainage basin.

Shown (1970) discussed the magnitude of error in using the rating method for estimating sediment yield at sites in Colorado, New Mexico, and Wyoming. Most estimated yields tended to be less than measured yields, and he attributed this difference to the subjective application of the ratings. The mean sediment-yield estimate for 28 sites was 1.4 acre-feet per year per square mile, whereas the mean determined from reservoir records was 1.73 acre-feet per year per square mile, giving a mean error of -19 percent. The maximum error for all sites studied was about -180 percent.

GEOLOGY AND HYDROLOGIC UNITS

A variety of rocks are exposed in the vicinity of the Jackpile mine. They consist of unconsolidated surficial deposits of Quaternary age, consolidated igneous rocks of Tertiary or Quaternary age, and consolidated sedimentary rocks (fig. 4) that range in age from Cretaceous to Triassic (Schlee and Moench, 1963a, 1963b). Unconsolidated surficial alluvial deposits along the Rio Paguate and Rio Moquino and the Jackpile sandstone of Late Jurassic age are the principal water-yielding units associated with the mine.

The surficial alluvial deposits, which include considerable amounts of eolian material, are about 80 feet thick locally and consist of clay, silt, sand, and gravel (Anaconda Copper Co., written commun., 1983). Alluvial deposits along the Rio Paguate and Rio Moquino are saturated and yield small quantities of fair-to-good water upstream from the mine.

Additional surficial deposits consist of gravel-covered pediments on the side and base of Mesa Chivato and colluvial deposits on the sides and bases of the mesas. Extensive talus, landslide deposits, and sheets of debris cover the steep hillsides at the western edge of the Jackpile mine and extend continuously along the eastern flanks of Mount Taylor from Wheat Mountain to Mesa Chivato. These deposits also cover parts of North and South Oak Canyon Mesas.

Igneous rocks exposed in the Laguna area are of late Tertiary to Quaternary age and consist of basalt plugs and basalt flows interstratified with alluvial and pyroclastic deposits. Older diabase dikes and sills occur locally, two of which may be clearly seen at the walls of the Paguate pits. Mount Taylor is a stratified volcano and is part of a northeast-trending belt of basaltic cones, plugs, and flows. Interstratified pyroclastic deposits and basalt flows form the cap on Mesa Chivato (Moench and Schlee, 1967) and pyroclastic deposits form the top of Wheat Mountain.

Other hydrologic units are the colluvial deposits and basalt flows and pyroclastic deposits in the Mount Taylor and Mesa Chivato areas. F. P. Lyford (U.S. Geological Survey, written commun., 1977) described springs flowing from the basalt caps on Mesa Chivato at the upper reaches of the Rio Paguate. It is likely that these springs, combined with flow from colluvial debris along the sides of Bear Canyon on Mesa Chivato, sustain base flow in the Rio Paguate. Similar conditions in Seboyeta and Bibo Canyons farther to the north probably produce the base flow in the Rio Moquino.

The consolidated sedimentary rocks shown in figure 4 crop out in an area between a strike line 10 miles southeast of the mine and a strike line 7 miles northwest of the mine. The rock units, which are successively older to the southeast, dip northwestward at about 90 feet per mile (Schlee and Moench, 1963a, 1963b). Few faults are present in the mine area and they have small displacements. The generalized thicknesses of the sedimentary rock units shown in figure 4 are the maximum thicknesses given by Schlee and Moench (1963a, 1963b). Departures from the thicknesses given in figure 4 that are mentioned elsewhere in this report may be more representative of specific localities.

SYSTEM	FORMATION OR GROUP	MEMBER OR TONGUE	THICKNESS (feet)
CRETACEOUS	Point Lookout Sandstone of Mesaverde Group	Hosta Tongue	100
	Crevasse Canyon Formation of Mesaverde Group	Gibson Coal and Dalton Sandstone Members	400
	Mancos Shale	Mulatto Tongue	400
	Crevasse Canyon Formation	Dilco Coal Member	85
	Gallup Sandstone of Mesaverde Group		80
	Mancos Shale		750
	Lower part of Mancos Shale	Includes three sandstone tongues of Mesaverde Group	270
	Dakota Sandstone		50
JURASSIC	Morrison Formation	Jackpile sandstone (economic use)	200
		Brushy Basin Member	270
		Westwater Canyon Member	50
		Recapture Member	40
	Bluff Sandstone		300
	Summerville Formation		90
	Todilto Formation		10
	Entrada Sandstone		120
TRIASSIC	Chinle Formation		

EXPLANATION

SANDSTONE

SHALE AND MUDSTONE

CARBONACEOUS MATERIAL

ANHYDRITE AND LIMESTONE

Modified from Schlee and Moench (1963a and 1963b). Only maximum thickness given.

Figure 4.--Generalized stratigraphic column of consolidated sedimentary rocks in the vicinity of the Jackpile mine.

Rocks exposed in and immediately around the Jackpile mine are as follows: the Brushy Basin Member, which is the uppermost member of the Morrison Formation and is exposed at the bases of some mesas; the Dakota Sandstone; and the Mancos Shale, which forms the tops of the locally high mesas. The uppermost part of the Brushy Basin Member is predominantly sandstone in the mine area. It is called the Jackpile sandstone (economic usage) and is both the ore-bearing body and the principal local bedrock aquifer. The Brushy Basin Member is underlain by the middle and lowest members of the Morrison Formation, which are the Westwater Canyon and Recapture Members, respectively.

The Jackpile sandstone is mostly fine to medium grained, poorly sorted to moderately well sorted, and friable. It is predominantly detrital quartz and has a chalky white cast due to kaolinization of feldspars prior to deposition of the Dakota Sandstone. Moench and Schlee (1967) observed discontinuous strata of greenish-gray bentonitic mudstone in most exposures of the Jackpile sandstone. They also stated that it is predominantly calcite cemented in its lower part and becomes increasingly clay cemented toward the upper part. Its thickness in the Jackpile mine ranges from 40 to 200 feet with an average of about 100 feet (Hydro-Search, Inc., written commun., 1981).

The Jackpile sandstone is overlain by tightly cemented sandstone in some areas, but elsewhere it is overlain by black shale. The black shale may represent a facies change in the Dakota Sandstone, or it may be a tongue of the Mancos Shale. In this report it will be called a shale in the Dakota Sandstone. The Dakota Sandstone is overlain by beds of tightly cemented sandstone and black shale in the Mancos Shale. Both formations overlying the Jackpile sandstone are extensively fractured. Fracture spacing at outcrops is only a few feet. Underlying the Jackpile sandstone is a mudstone unit in the Brushy Basin Member. In some areas, the mudstone is composed of fine sand- to silt-size fragments embedded in a clay matrix, but in other areas it is predominantly composed of swelling-type clays (Moench and Schlee, 1967).

The Dakota Sandstone and Mancos Shale vary in thickness in the Jackpile mine, depending mostly on the topography. The Dakota Sandstone averages about 45 feet thick. The Mancos Shale is not present on lower mesas, but is about 50 to 75 feet thick at the northwest and west-central part of the mine, and as much as 300 feet thick near Gavilan Mesa. The mudstone unit in the Brushy Basin Member is about 200 feet thick.

The lower hydrologic boundary in the local ground-water system probably is the mudstone unit underlying the Jackpile sandstone, as will be discussed later in the report. Recharge through fractures may occur in the otherwise almost impermeable rocks overlying the Jackpile aquifer. The recharge may occur locally in the mine area, as well as at higher altitudes where these rocks are buried beneath other sedimentary rocks and more permeable colluvial debris and pyroclastic deposits. Most recharge probably occurs at the higher altitudes north and west of the mine, where there is likely to be more precipitation and less evapotranspiration. Few data, however, are available regarding recharge in the Laguna area.

GROUND WATER

Underflow and Recharge

An estimate was made of the recharge rate in the Rio Paguate drainage basin by summing base flow and underflow and assuming that change in ground-water storage is negligible. Underflow may occur in the vicinity of the downstream Rio Paguate gaging station via the alluvium, Jackpile sandstone, and underlying rocks (bedrock other than Jackpile sandstone).

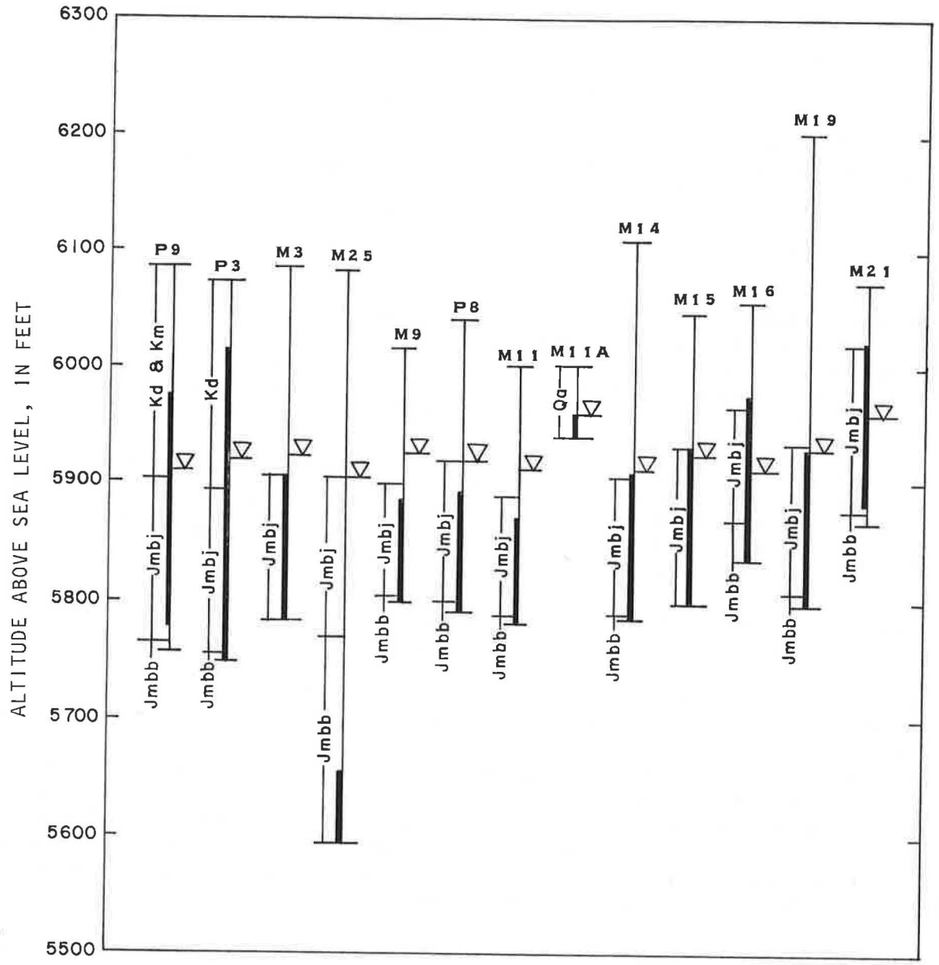
Alluvial underflow cannot be determined at the exact location of the gaging station because data are insufficient. Data are used from wells located near the confluence of the Rio Paguate and Rio Moquino for estimating underflow at the downstream station. An aquifer test at well M4C (described in a later section) indicated hydraulic conductivity (K) of the alluvium to be 23 feet per day. Saturated thickness (b) is about 20 feet and width (w) is about 1,000 feet. Hydro-Search, Inc. (written commun., 1979) determined the gradient of the stream to be about 0.02 at this location. The hydraulic gradient (I) is approximated by assuming it is equal to the gradient of the stream. Underflow is approximated as $Q = KIbw = 9{,}000$ cubic feet per day, which is equivalent to an annual flow of about 40 cubic feet per second-days. Annual base flow is 215 cubic feet per second-days (table 7). Base flow plus underflow through alluvium is, therefore, about 250 cubic feet per second-days annually.

Underflow through bedrock cannot be determined because data are insufficient. Saturated zones and hydraulic gradients are not known, and hydraulic conductivities of bedrock other than the Jackpile sandstone are not known. Positions of ground-water divides may not correspond to topographic divides, so interbasin flow may occur. For purposes of this report, it is assumed that neglecting underflow through bedrock does not introduce significant error in estimating the recharge rate in the Rio Paguate drainage basin. This assumption probably is reasonable because: (1) The mudstone strata underlying the Jackpile sandstone form the lower hydrologic boundary throughout much of the southeastern part of the basin; and (2) the top of the mudstone generally crops out northeastward across the basin in the vicinity of the Rio Paguate stream-gaging station (located near the south edge of the mine), so that much of the water in the Jackpile sandstone probably discharges to the alluvium or to streams upgradient from the station.

The recharge rate is estimated as the sum of base flow and underflow through alluvium, which is about 250 cubic feet per second-days (about 500 acre-feet) annually in the Rio Paguate drainage basin upgradient from the gaging station. This is equivalent to about 0.1 inch per year throughout the 107-square-mile drainage area. Rates probably are greater at higher altitudes on Mount Taylor and Mesa Chivato and may be less at lower altitudes. Recharge probably is greater in colluvium on the flanks of mesas and in alluvium at valley bottoms than it is on exposed bedrock.

Wells in the Jackpile Mine

Most wells in the Jackpile mine are open to one or the other of the two principal aquifers in the area, which are the alluvium and the Jackpile sandstone (figs. 5-8). None are completed solely in bedrock overlying the Jackpile sandstone. Well M25 near the North Paguate pit is completed in the mudstone unit of the Brushy Basin Member underlying the Jackpile sandstone. Wells M17 and M24 are drilled into mine waste rock.



EXPLANATION

Qa	ALLUVIUM
Kd	DAKOTA SANDSTONE
Km	MANCOS SHALE
Jmbj	JACKPILE SANDSTONE OF BRUSHY BASIN MEMBER OF MORRISON FORMATION
Jmbb	LOWER PART OF BRUSHY BASIN MEMBER OF MORRISON FORMATION UNDERLYING JACKPILE SANDSTONE

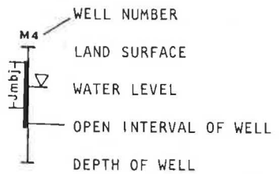
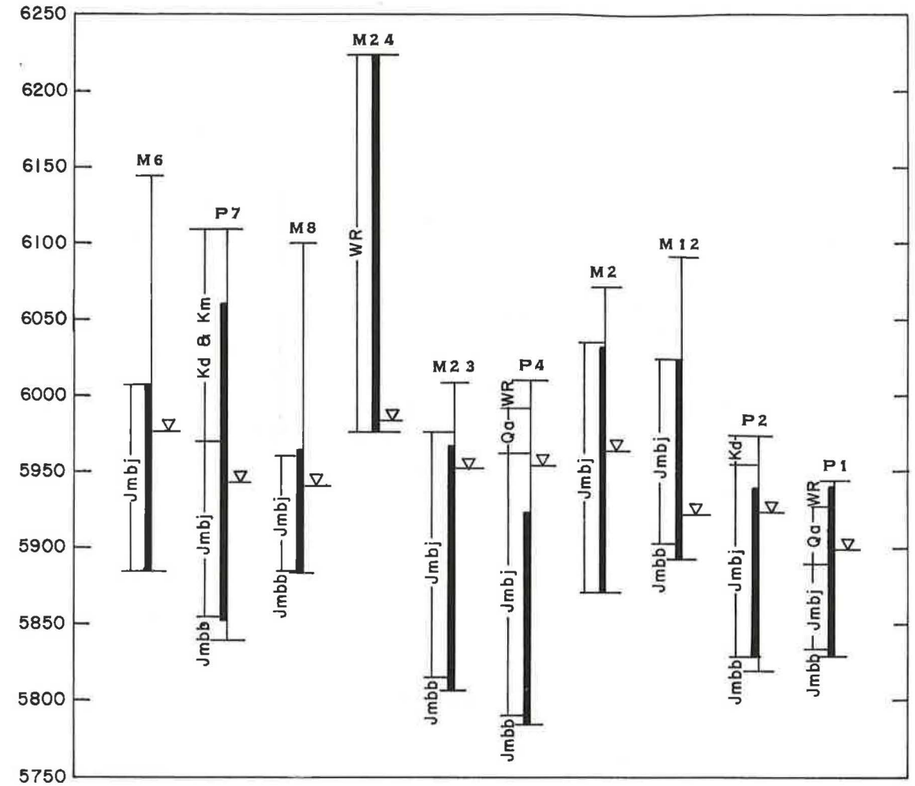


Figure 5.--Well construction and water levels in wells, northern part of the Jackpile mine area.



EXPLANATION

WR	WASTE ROCK
Qa	ALLUVIUM
Kd	DAKOTA SANDSTONE
Km	MANCOS SHALE
Jmbj	JACKPILE SANDSTONE OF BRUSHY BASIN MEMBER OF MORRISON FORMATION
Jmbb	LOWER PART OF BRUSHY BASIN MEMBER OF MORRISON FORMATION UNDERLYING JACKPILE SANDSTONE

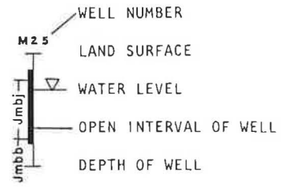
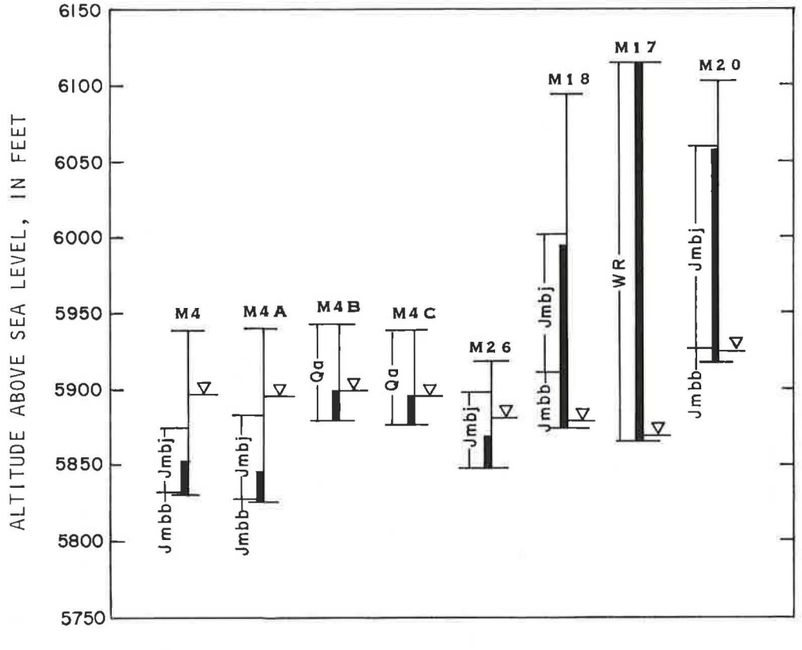


Figure 6.--Well construction and water levels in wells, west-central part of the Jackpile mine area.



EXPLANATION

WR	WASTE ROCK
Qa	ALLUVIUM
Jmbj	JACKPILE SANDSTONE OF BRUSHY BASIN MEMBER OF MORRISON FORMATION
Jmbb	LOWER PART OF BRUSHY BASIN MEMBER OF MORRISON FORMATION UNDERLYING JACKPILE SANDSTONE

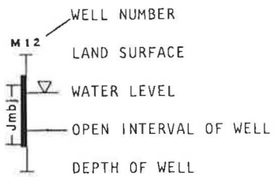
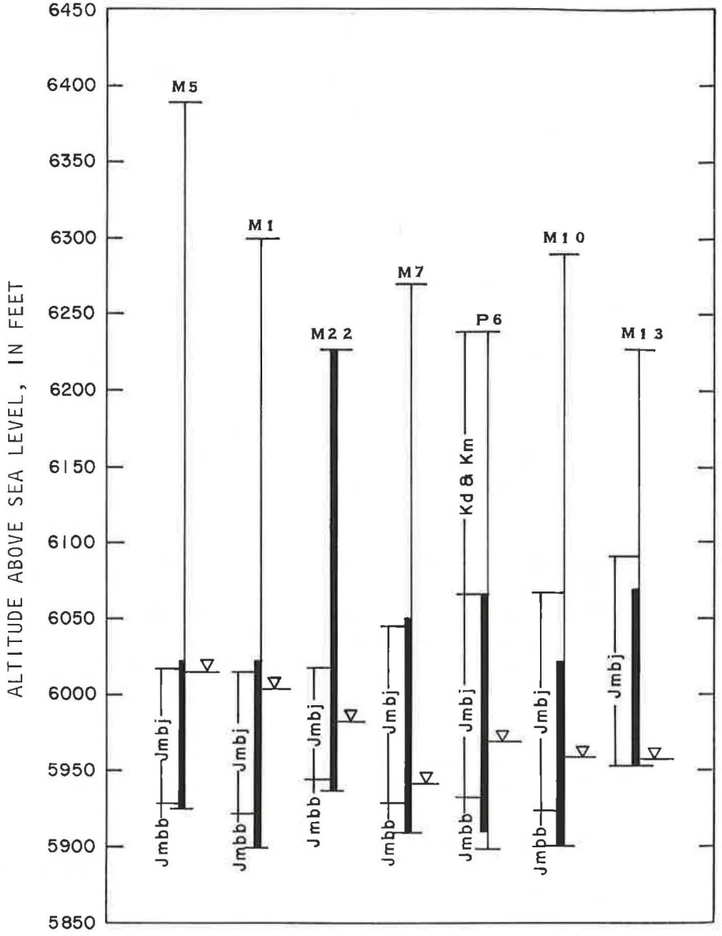


Figure 7.--Well construction and water levels in wells, east-central part of the Jackpile mine area.



EXPLANATION

Kd	DAKOTA SANDSTONE
Km	MANCOS SHALE
Jmbj	JACKPILE SANDSTONE OF BRUSHY BASIN MEMBER OF MORRISON FORMATION
Jmbb	LOWER PART OF BRUSHY BASIN MEMBER OF MORRISON FORMATION UNDERLYING JACKPILE SANDSTONE

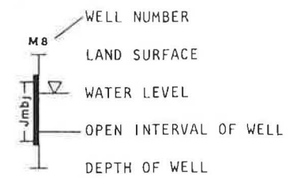


Figure 8.--Well construction and water levels in wells, southwestern part of the Jackpile mine area.

Wells were installed for two hydrologic studies at the Jackpile mine. The "P" series of 11 wells was constructed in 1977 by Hydro-Search, Inc., in order to examine water-quality effects of holding ponds on the ground-water system. The "M" series of 30 wells was constructed about 1980 by Hydro-Search, Inc., as part of a general hydrogeologic study. Locations are shown on plate 1 for wells completed in bedrock and waste rock. Seven observation wells also were constructed for aquifer tests at several of the M wells. Well M4C is an observation well drilled near well M4 (pl. 1).

The P-series wells have 2-inch-diameter PVC casing in the drillholes, which is slotted and gravel packed through the aquifers. Cement depths are not reported for P wells. Well P5 presently is inaccessible, and well P11 has been destroyed. The M-series wells have 5 9/16-inch-diameter steel casing, which is slotted and gravel packed through the aquifers. The wells were cemented from the tops of the gravel packs to ground surface, except for wells completed in waste rock and well M22 (Anaconda Copper Co., written commun., August 1981).

Diagrams showing well construction, formations penetrated, and positions of water levels are shown in figures 5-8. The diagrams show equal spacing between wells. They are intended to illustrate relative positions of strata contacts and water levels and should not be construed as geologic sections. Water levels were measured in June 1981.

Wells in the northern and east-central parts of the mine (figs. 5 and 7) generally have water levels above the top of the Jackpile sandstone, whereas wells in the west-central and southwestern parts of the mine area generally have water levels within this stratum (figs. 6 and 8). The dip of the rocks causes the Jackpile sandstone to be below land surface north and west of the mine. In these areas, it is completely saturated.

Potentiometric Surface and Directions of Ground-Water Flow

Regional ground-water flow in the Laguna Pueblo is southward toward the Rio San Jose and eastward toward the Rio Puerco (F. P. Lyford, U.S. Geological Survey, written commun., 1977). The emphasis of this report is on local flow, and descriptions are based primarily on a potentiometric-surface map of the Jackpile mine.

Water levels and well depths were measured in all wells reported as being open to the Jackpile sandstone, two wells completed in waste rock, and one well completed in the lower part of the Brushy Basin Member (table 14). Measurements were made with steel tape from June 10 through June 12, 1981. Accuracy is about ± 0.05 foot for most wells. It is about ± 0.2 foot for well M20, and about ± 3 feet for well P6. Water-level altitudes are given in tenths of a foot for P wells because only ground-surface altitudes at the wells are available. Altitude differences for previously measured water levels and those measured for the present study are shown in table 14.

The water levels represent composite hydraulic heads because the wells are open to many feet of saturated rocks. Wells open to the Jackpile sandstone only are used to indicate general directions of ground-water flow and general ground-water gradients in that stratum because most are open to the entire thickness of the stratum. A water level at altitude 5,960 feet was measured in well P11 (now destroyed) in March 1979, and this measurement also was used in constructing a potentiometric-surface map for the present report.

Well locations and the potentiometric surface for the Jackpile sandstone in June 1981 are shown on plate 1. Flow into the mine area primarily is from high areas on the flanks of Mount Taylor to the west and probably from Mesa Chivato to the north. Much of the flow from the west is intercepted by the North and South Paguate pits and by pumpage from the P10 underground mine.

Seepage faces are obvious on the walls of the North and South Paguate pits. The top of a seepage face was at altitude 5,948 feet on a waste-covered section of bedrock at the north side of the South Paguate pit, and a pond in the lowest part of the pit had a water-surface altitude of 5,927 feet (pl. 1). The altitudes were measured in June 1981. They were below water-level altitudes measured in nearby wells. Water-surface altitudes were not measured in other pits, but the lowermost pond in the North Paguate pit was observed to be below the top of seepage faces. Closed potentiometric contours were therefore drawn around all pits and indicate ground-water discharge into the pits. Water loss is by evaporation and use of pond water for dust suppression on roads.

The approximate position of the top of the Jackpile sandstone at the edge of the pits is shown on plate 1. Topographic contours could not be used because some high areas at pit edges are extensive piles of waste rock. Most cross sections drawn by Anaconda Copper Co. (written commun., 1980) show "edges of excavation," and these are shown on plate 1. The top of the Jackpile sandstone at the approximate pit edge is illustrated where the edges of excavation are not shown on the cross sections. Where neither of the boundaries were reported, the edge is not shown. Both the "edges of excavation" and the edge of the Jackpile sandstone are shown at the northeast end of the Jackpile pit because the top of the stratum underlies much of the excavated surface at this location. Few detailed cross sections are available for the North Paguate pit, so its boundaries are not shown.

The positions are approximate for the ground-water divides near the pits because there are few wells at pit edges. Potentiometric contours at pit edges are simplified. With extensive data-point control, many closely spaced contours would have to be drawn near seepage faces.

Table 14.--Water levels in wells at the Jackpile mine

[All values are in feet. All wells are open to the Jackpile sandstone except for those noted]

Well	Height of casing above ground level	Depth to water in June 1981 [1]	Altitude of water level in June 1981	Difference from previous levels [2]	Depth of well [1]
M1	2.0	298.59	6003.61	- 3.01	403.1
M2	1.6	110.30	5962.61	+ 2.18	201.6
M3	1.7	162.68	5924.04	+ .22	302.7
M4	2.3	44.83	5896.77	+ .65	110.7
M5	2.8	378.52	6014.57	- 1.30	467.7
M6	2.2	170.21	5976.08	-18.66	261.8
M7	2.5	327.59	5940.96	- .05	360.1
M8	2.1	162.18	5940.29	- 3.05	217.8
M9	2.2	90.94	5926.98	- .29	219.9
M10	2.6	231.47	5959.33	.00	289.9
M11	2.5	90.93	5912.95	- .35	222.4
M12	2.4	173.74	5920.86	- .24	201.5
M13	2.5	270.37	5955.53	-	270.8
M14	2.5	199.13	5912.76	- 1.44	324.2
M15	2.3	123.12	5925.70	- 5.22	251.3
M16	2.1	147.47	5911.51	- .72	219.4
M17 [3]	2.7	249.02	5867.86	-	254.1
M18	2.2	217.31	5878.95	-	219.3
M19	2.7	274.85	5930.21	+ .27	406.9
M20	2.5	180	5925.2	- .2	188.4
M21	2.4	114.43	5961.17	- .14	204.0
M22	2.8	244.77	5982.64	+ 1.04	290.7
M23	2.3	58.61	5951.52	- .93	202.9
M24 [3]	3.0	244.40	5981.45	-	246.9
M25 [4]	1.6	179.34	5906.06	-	-
M26	1.8	38.79	5881.11	- .26	67.1
P1	0.5	45.98	5897.9	- 1.8	86.2
P2	2.1	52.70	5923.1	+ 1.3	143.2
P3	0.5	151.93	5921.5	- 2.9	313.4
P4	1.6	57.08	5953.0	- 3.0	171.6
P6	1.4	270	5969	-23	-
P7	1.7	168.52	5942.5	-40.3	269.9
P8	0.7	122.19	5920.5	- 2.0	250.8
P9	2.4	177.33	5912.2	- 9.0	332.7

[1] Depth referenced to top of casing.
[2] Water levels measured in December 1980 (M wells) and March 1979 (P wells) subtracted from those measured in June 1981.
[3] Completed in backfill.
[4] Completed in Brushy Basin Member of the Morrison Formation below Jackpile sandstone.

Water-table surfaces could not be drawn inside pits due to lack of data. A pond in the South Paguate pit, with water-surface altitude measured at 5,976.3 feet (pl. 1) in June, 1981, is higher than the pond in the deeper part of the pit and higher than water levels in some wells. The higher ponds probably are due to surface runoff and water from near-surface infiltration discharging into them. Infiltrating water from the higher ponds probably flows through backfill material toward the lower ponds.

Water-level differences shown in table 14 generally show lower hydraulic heads for the later measurements. Differences of about 2 to 3 feet probably are not significant. They may be due to different measuring techniques or seasonal changes. Significant hydraulic-head declines in wells M6 (18 feet), P7 (40 feet), and P6 (23 feet) probably result from discharge into the North and South Paguate pits. Hydraulic-head changes in well M1(-3 feet), M22(1 foot), and M7(-.05 foot) are small, indicating that pumpage from the P10 underground mine presently has less effect on hydraulic heads near wells M6, P7, and P6 than does discharge into the Paguate pits. Discharge into the North Paguate pit probably caused the hydraulic-head declines in wells P3 (3 feet), P9 (9 feet), and M8 (3 feet).

Well M25 is 50 feet from well M3 and is completed in a sandstone bed underlying a mudstone unit approximately 100 feet thick. The mudstone underlies the Jackpile sandstone in which well M3 is completed. The water level in well M3 was 17.1 feet higher than that in well M25 in August 1981, indicating potential for downward flow at this location. Well M25 penetrates about 180 feet more strata than well M3, indicating a gradient of about 0.1 in the vertical.

The local flow system probably is more complex than is shown on plate 1. Even though 33 wells are available for control in drawing potentiometric contours in the Jackpile sandstone, data are insufficient to show the following: effect of local topographic and mining features; gradients near streams, particularly the Rio Moquino and the downstream reach of the Rio Paguate; and flow in the northern, northwestern, and southeastern parts of the mine.

Potentiometric contours at Gavilan Mesa are highly interpretive, with only wells M19, M20, and M21 available for control. Because Gavilan Mesa is the highest area at the eastern part of the mine, contours were drawn as indicating local recharge through the extensively fractured rocks comprising Gavilan Mesa.

The gradients drawn around the northwest and west side of Gavilan Mesa are about 1 to 2 orders of magnitude greater than would be expected if a hydraulic conductivity of 0.3 foot per day were used for the Jackpile sandstone (explained in the following section), with a recharge-discharge rate of 0.1 inch per year. The water level in well M19 (fig. 5) shows nearly complete saturation of the sandstone at this location at an altitude of 5,930.2 feet. Contours from 5,930 to 5,960 feet on plate 1 represent saturation of the Dakota Sandstone on the mesa. Observations of outcrops showed the rocks to be tightly cemented; the most effective porosity apparently is due to fracturing. Hydraulic conductivity could be 2 orders of magnitude less than that in the Jackpile sandstone, thus producing gradients approximating those shown.

A well on Gavilan Mesa completed in the Jackpile sandstone would show whether or not the interpretation illustrated on plate 1 is correct. Wells at the same location, open only to fractures in the Dakota Sandstone and in the Mancos Shale, might show one or more water tables higher than that in the Jackpile sandstone. If so, local recharge might be expected in other areas of the mine, including waste dumps.

The ground-water divide indicated by the 5,970-foot potentiometric contours south and east of the South Paguate pit probably is either due to: (1) Nonequilibrium conditions resulting from withdrawal in the P10 underground mine and losses to the South Paguate pit, thus lowering a potentiometric surface that was higher when hydraulic heads were greater at the western part of the mine; or (2) equilibrium conditions that reflect local recharge. Similar explanations may be made for the ground-water divides indicated by the 5,920-foot contours east of the North Paguate pit, and perhaps some areas around the Jackpile pit. Nonequilibrium conditions are likely to prevail in some of the mine area, however, as indicated by the recent large changes in some ground-water levels described earlier in this section.

Well M17 is in a waste dump at the southwest end of the Jackpile pit (pl. 1). The dump extends southward to a small mesa on which well M18 is located. Data are insufficient to determine whether flow in the vicinity of well M18 is toward the dump or toward the Rio Paguate. Potentiometric contours between wells M16 and M18 were, therefore, truncated.

Streams gain water near the center of the mine, as indicated by the potentiometric contours. Gains of about 20 gallons per minute were estimated near the confluence of the Rio Moquino and Rio Paguate, whereas losses were estimated in the Rio Paguate from the western edge of the mine to a point about 1,000 feet above its confluence with the Rio Moquino.

The potentiometric surface shown on plate 1 does not reflect losing areas, which would be expected to result in ground-water mounding along the stream. Contours could not be drawn with available data to reflect ground-water mounding without producing unreasonably large gradients. The stream channel was changed during mining in the vicinity of wells M23 and P4 and is now underlain by about 40 feet of waste rock. The waste probably is permeable enough so that there is little ground-water mounding.

In summary, normal ground-water flow has been changed in the Jackpile mine by pit excavations, pumpage from underground mines, and probably by streambed alteration. Natural variations in hydraulic conductivity are likely to also produce local changes in flow. Extensive well control would be needed to define the ground-water system accurately. In general, ground water enters the mine primarily from the west and north and flows mostly toward pits, the P10 underground mine, and the Rio Paguate and Rio Moquino. Flow in the southeastern part of the mine is not defined, but is probably toward the Rio Paguate or toward the southeast.

Aquifer Tests

Water-transmitting characteristics of aquifers were determined at five sites in the Jackpile mine. A submersible pump was installed in four wells, and constant-rate pumping continued until completion of tests. A fifth well (M25) was "slug tested," using a piston to increase the hydraulic head in the well. Hydraulic-head data were collected continuously at each site from both the pumped well and a nearby observation well. Pressure transducers were used, and readings were checked at various intervals by measurements with steel tape.

Strata and sites tested were the following: the alluvium at the confluence of the Rio Paguate and Rio Moquino; the Jackpile sandstone at the northwest, northeast, and southwest parts of the mine; and a sandstone bed in the predominately mudstone part of the Brushy Basin Member at the northwest part of the mine. Test data were analyzed as follows: well M2 by the nonequilibrium method with allowance for delayed yield from storage (Boulton, 1963); wells M4C and M3 by the curve-matching nonequilibrium method (Theis, 1935); well M21 by the nonequilibrium method with allowance for water stored in the finite-diameter well bore (Papadopulos and Cooper, 1967); and well M25 by the instantaneous-charge method (Cooper, Bredehoeft, and Papadopulos, 1967).

Description and results of the tests are given in table 15. Distances between discharge and observation wells were obtained from Hydro-Search, Inc., (written commun., 1981). Well locations are shown on plate 1. The hydraulic conductivity of the Jackpile sandstone throughout much of the mine probably is about 0.3 foot per day, as indicated by the tests at wells M2 and M3. Hydraulic conductivity of the alluvium is almost 2 orders of magnitude greater than the bedrock strata tested, probably because of larger interconnected pore size and lack of cementation between grains.

The hydraulic conductivity of 0.33 foot per day for the sandstone bed in the Brushy Basin Member at well M25 probably is much larger than that for the mudstone part of the member. Mudstone beds about 100 feet thick separate the sandstone bed from the overlying Jackpile sandstone (Hydro-Search, Inc., written commun., 1981). Maximum water-level change was 0.03 foot in well M25 when 61.6 feet of drawdown was produced in the Jackpile sandstone after 4 days of pumping at well M3. The wells are 50 feet apart. The small hydraulic-head change in well M25 may have been mostly due to a change in barometric pressure during the test. The predominantly mudstone part of the Brushy Basin Member, which underlies the alluvium and stream channels in the area, probably forms the lower hydrologic boundary in the mine, as indicated by the lack of hydraulic connection with the Jackpile sandstone.

The small storage coefficients for the Jackpile sandstone may indicate a confined system. However, water levels in wells M2 and M21 were below the top of the aquifer, so the Dakota Sandstone did not cause the confined conditions at the well sites. The Jackpile sandstone contains discontinuous strata of bentonitic mudstone, and clay content increases upward in the stratum (Moench and Schlee, 1967). The mudstone and clay cement probably cause locally confined conditions.

Table 15.--Summary of aquifer tests at five wells in the Jackpile mine

Well	M2	M3	M21	M4C	M25
Strata tested	Jackpile sandstone	Jackpile sandstone	Jackpile sandstone	Alluvium	Sandstone[1]
Distance, in feet, between discharge and observation wells	54	44	57	[2]52	--
Date test began	8/19/81	8/24/81	8/18/81	8/22/81	8/19/81
Altitude of water level before test (feet)	5964.6	5924.5	5961.3	5897.4	5907.4
Maximum drawdown (feet)	37.0	61.6	36.7	1.9	--
Duration of test (hours)	43	88	24	17	2
Pumping rate (gallons per minute)	5.1	15.3	0.25	8.6	--
Saturated thickness (feet)	93	120	81	19	60
Transmissivity (feet squared per day)	24	47	2.0	430	20
Hydraulic conductivity (feet per day)	0.28	0.39	0.024	23	0.33
Storage coefficient X 10^4 (dimensionless)	1.9	2.9	0.20	19	1.0

[1] Sandstone bed in predominantly mudstone part of the Brushy Basin Member of the Morrison Formation.
[2] Observation well used was M4B.

Flow through Backfill and Waste Piles

Few data are available to accurately describe flow through backfill (in pits) and waste piles (located outside pits) because of the problems involved in well completion. Two wells, M17 and M24, were drilled into backfill, but difficulties in completing them prevented proper grouting of the annuli.

Well M17 was drilled into backfill at the southwest end of the Jackpile pit (pl. 1). The water-surface altitude was 5,968 ±1 feet at a pond about 500 feet north of the well in August 1981. This was within 1 foot of the water level in the well. The greater hydraulic head at these sites was not determined because of the large error range in pond-surface altitude. Water may be flowing through backfill northward toward the pond or from the pond toward lower areas to the west or south.

Well M24 is located at the north end of the South Paguate pit (pl. 1) and had a water-level altitude of 5,981 feet in June 1981. The water-level altitude is higher than that of the water surface in the lowermost pond in the pit and higher than hydraulic heads in the Jackpile sandstone near the well. Well M24 was drilled through backfill into what was formerly a holding pond for water pumped from mine workings. The water level may represent ground-water mounding (or perched water) due to the holding pond, local recharge to the backfill, or surface flow down the well annulus.

Flow from the Rio Paguate to well M24 is not likely because the water table in the alluvium was at an altitude of 5,970 feet in March 1979 (Hydro-Search, Inc., written commun., 1979) at a point about 1,500 feet downstream from wells M23 and P4. Discharge from the backfill at well M24 probably is toward the South Paguate pit, toward the Rio Paguate, or both. A hydraulic conductivity of 190 feet per day was reported for backfill at well M24 by Hydro-Search, Inc. (written commun., 1981).

No wells are completed in waste piles, so it is not known if the piles are unsaturated, periodically saturated, or constantly saturated. Runoff was observed flowing into small cavities atop two waste piles during intense rainfall, indicating much of the recharge probably is through very permeable vertical channels below surface depressions rather than uniform infiltration over the surface of the piles. No seepage faces were observed at the bases of the piles during dry weather because saturation may be limited and of short duration or flow may be downward through the bases of the piles to the underlying bedrock or alluvium. The waste piles may have large enough hydraulic conductivity so that infiltrating water is discharged rapidly, preventing long-term saturation.

WATER BALANCE

A water balance is useful for estimating evapotranspiration in the Rio Paguate drainage basin. A general form of the water-balance equation may be written as:

$$P = R + \Delta GW + U + ET$$

where:

P is precipitation;
R is runoff;
ΔGW is change in ground-water storage;
U is underflow; and
ET is evapotranspiration.

The change in ground-water storage is assumed to be negligible on an annual basis. Total underflow is about equal to underflow through alluvium, as described previously. Therefore, the underflow is about 40 cubic feet per second-days annually, which is equivalent to about 0.01 inch per year over the 107-square-mile drainage area upstream from the gaging station near the southern boundary of the mine area. The underflow was added to runoff and the sum subtracted from precipitation to estimate evapotranspiration for water years 1977 through 1980 (table 16). Water losses by evapotranspiration are very large, constituting about 98 percent of precipitation.

Table 16.--Water balance for the Rio Paguate drainage basin upstream from the gaging station at the southern boundary of the Jackpile mine

[Values are in inches, except numbers in parentheses are percent of precipitation]

Water year	Precipitation	Runoff plus underflow	Evapo-transpiration
1977	8.38	0.197	8.2 (98)
1978	7.90	.147	7.7 (97)
1979	11.60	.179	11.4 (98)
1980	9.85	.120	9.7 (98)
Mean	9.43	.161	9.2 (98)

WATER QUALITY

This description of water-quality conditions within and in the vicinity of the Jackpile uranium mine is based on a review of chemical analyses performed on water samples collected by Anaconda Copper Co., the U.S. Bureau of Indian Affairs, and the U.S. Geological Survey. The surface-water and ground-water sampling sites are shown in figure 9.

More than 500 samples were collected by Anaconda Mining Co. for analyses of major dissolved constituents at several surface sites from 1962 to 1981. Surface-water samples were collected on the Rio Paguate and the Rio Moquino at the following locations: (1) on each stream upstream from the mine area, (2) on each stream just inside the mine area's upstream boundary, (3) on each stream within the mine area just upstream from the confluence, (4) on the Rio Paguate within the mine area but downstream from the mouth of the Rio Moquino, and (5) at Paguate Reservoir about 5 miles downstream and outside the mine area. A few additional surface-water samples were collected from miscellaneous locations in the vicinity of the mine, including pools within the mine pits.

Ground-water samples selected for this description were collected by Anaconda Copper Co. periodically from water-supply wells within the mine area from 1976 to 1981 and also from each of the 11 P-series test wells during 1977 and 1978. The P-series wells were installed in 1977 as water-quality sampling wells to study ground-water interactions with the holding ponds.

About 150 water analyses performed by the Bureau of Indian Affairs and about 20 selected samples from the files of the Geological Survey were reviewed and used collectively with Anaconda Copper Co.'s data for this study. The water analyses of the Bureau of Indian Affairs and Geological Survey were performed mainly on water samples collected from outside the mining area. Because of the large number of analyses and the small ranges of chemical concentrations found at each site, it was possible to judge and to select typical samples to represent the water-quality conditions at the different sites for the period sampled. No obvious trends were detected after examining the data, so the typical samples represent prevailing conditions.

Chemical analyses of water samples collected within the mined area before the mining began in 1953 were not found in the data search, so the water-quality conditions described are for the mining period between 1962 and 1980.

Dissolved Solids and Dominant Ions

Stiff diagrams (Stiff, 1951) were used to compare the differences in major dissolved-ion concentrations among the selected sampling sites shown in figure 9. The Stiff diagrams are not included in this report but are available in the files of the U.S. Geological Survey in Albuquerque, New Mexico.

An arithmetic average of the specific conductances measured during the sampling period at each site was used as a guide to select chemical analyses to represent the water at each site. The analyses selected had specific-conductance values similar to these averages and were assumed to approximate the average concentrations of the chemical constituents that would be computed for the sites for the periods the sites were sampled. The Stiff diagrams were constructed using the ionic concentrations of these selected analyses.

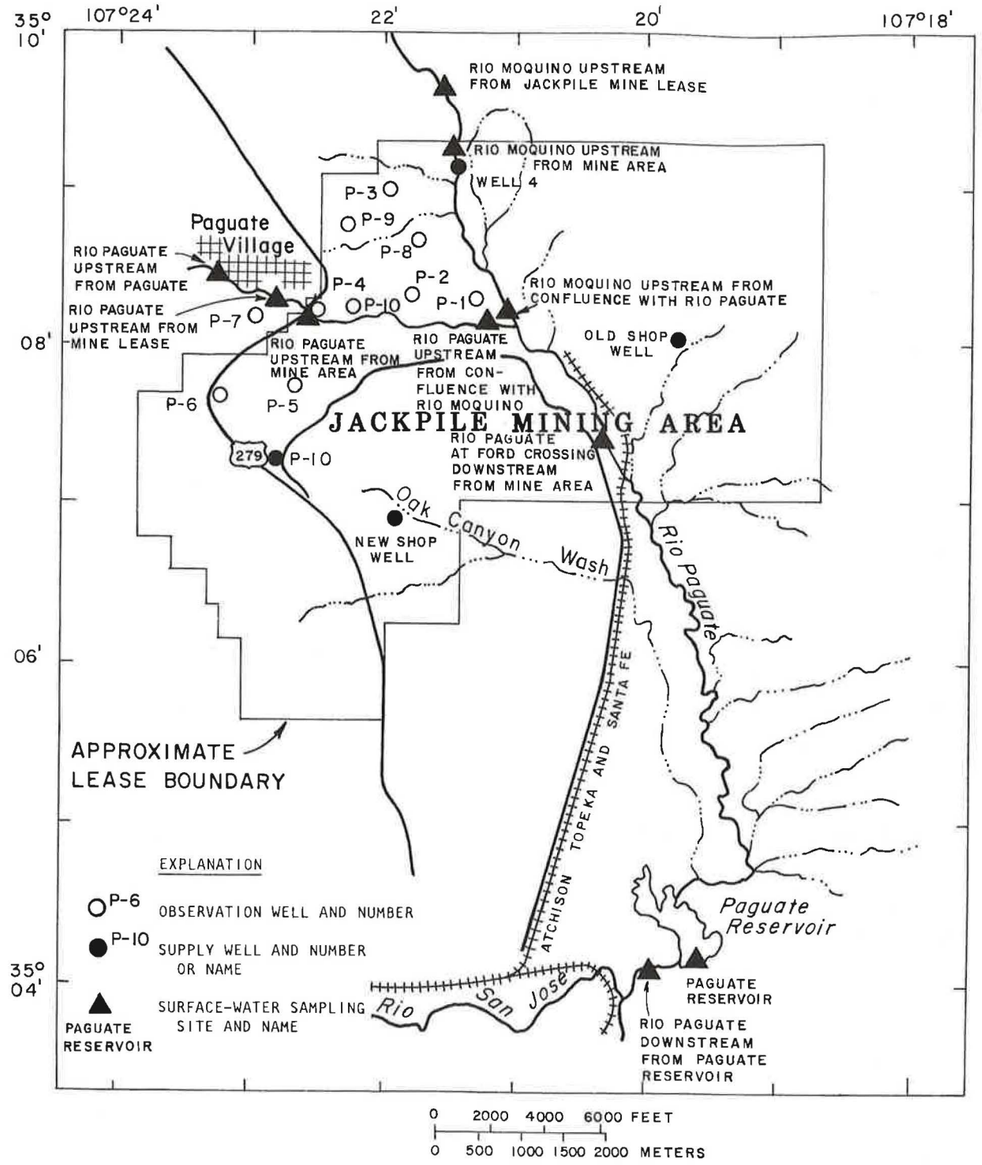


Figure 9.--Location of wells and selected water-quality sampling sites, Jackpile mine area and vicinity.

The average specific conductance for each of the sampling sites and the collection dates of single samples that are representative of the typical water-quality condition at each site are given in table 17.

Table 17.--Average specific conductance in water at each sampling site, Jackpile mine area and vicinity

Sampling site (fig. 9)	Average specific conductance (microsiemens per centimeter at 25°Celsius)	Analysis selected (month-day-year)
Rio Paguate upstream from Paguate	344	10-30-78
Rio Paguate upstream from Jackpile mine lease	708	03-03-80
Rio Paguate upstream from mine area	788	10-02-80
Rio Paguate upstream from confluence with Rio Moquino	1,040	11-06-79
Rio Paguate at ford crossing downstream from mine area	2,240	02-24-71
Paguate Reservoir	2,190	11-11-75
Rio Paguate downstream from Paguate Reservoir	2,310	01-10-78
Rio Moquino upstream from Jackpile mine lease	2,010	05-21-79
Rio Moquino upstream from mine area	1,870	05-19-71
Rio Moquino upstream from confluence with Rio Paguate	2,460	11-06-79
Well 4	1,266	05-19-71
New shop well	2,014	12-04-80
Old shop well	2,183	06-03-80

The streamflow in the Rio Paguate upstream from the Rio Moquino contains concentrations of dissolved solids that average from less than 575 mg/L (milligrams per liter) upstream from the community of Paguate to about 700 mg/L upstream from the confluence with its main tributary, the Rio Moquino (table 18). The dominant ions are calcium and bicarbonate, indicating dissolution of calcareous minerals in the streamflow. The Stiff-diagram analysis shows a gradual increase in the downstream direction of calcium, magnesium, bicarbonate, and sulfate, which indicates dissolution of gypsum and dolomite minerals.

Table 18.--Mean concentrations of dissolved solids in water from the Jackpile mine area and vicinity

Sampling site	Dissolved solids (milligrams per liter)
Rio Paguate upstream from mine area	less than 575
Rio Paguate upstream from the confluence with Rio Moquino	700
Rio Moquino upstream from mine area	1,600
Rio Moquino upstream from confluence with Rio Paguate	1,900
Rio Paguate at ford crossing downstream from mine area	2,000
Paguate Reservoir	2,000
Well 4	900
New shop well	1,400
Old shop well	1,500

The streamflow in the Rio Moquino contains greater concentrations of dissolved solids than does the Rio Paguate. The mean dissolved-solids concentrations in the Rio Moquino range from 1,600 mg/L upstream from the mine area to 1,900 mg/L just upstream from its confluence with the Rio Paguate.

The flow in the Rio Moquino contains calcium, magnesium, and sodium concentrations in nearly equal proportions and sulfate concentrations that are greater than bicarbonate or chloride concentrations. A mixture of weathered shale and sandstone is the probable source of these ions. These water-quality characteristics prevail in the Rio Paguate downstream from the mouth of the Rio Moquino. The average dissolved-solids concentration increases to about 2,000 mg/L in the downstream reach of the Rio Paguate.

On the basis of the concentrations of dissolved solids, flow in the upstream reach of the Rio Paguate is considered to be fresh, whereas the flow in the Rio Moquino and the downstream reach of the Rio Paguate is considered to be slightly saline according to the U.S. Geological Survey's salinity classification (table 23 at back of report).

The degree of salinity in these two streams generally is acceptable for the local irrigation, livestock, and domestic uses according to criteria set by the U.S. Environmental Protection Agency (1972, 1977b). The sulfate concentrations exceed the recommended criterion of 250 mg/L (U.S. Environmental Protection Agency, 1972, 1977b) for drinking-water supplies in the Rio Moquino and in the downstream reach of the Rio Paguate; however, this criterion is set to prevent undesirable odors or taste and to prevent temporary laxative effects on humans.

The Stiff-diagram analysis for ground water from well 4 and wells P3 through P8 indicates one pattern in which the concentrations of sodium, bicarbonate, and sulfate predominate. This may indicate that the ground water was in contact with clay and shale. The Stiff diagrams for the ground water from the New shop well, the Old shop well and wells P9 and P10 indicate another pattern in which the proportions of sodium and sulfate are much greater than those proportions in water from the first group of wells. This may indicate that the ground water may be associated with more oxidized clay and shale. The Stiff-diagram patterns for wells P1, P2, and P10 indicate greater proportions of calcium and magnesium. This may indicate the presence of gypsiferous or dolomitic minerals in the water-bearing zones in which these wells are completed.

This entire group of wells produces waters with dissolved-solids concentrations between 900 and 1,500 mg/L (table 18). The water is either fresh or slightly saline and is considered acceptable for the local customary irrigation, livestock, and domestic uses.

The slightly saline water in the Rio Moquino and downstream reach of the Rio Paguate, as compared to areas of greater rainfall, is less saline than the water found in certain other streams within a 60-mile radius of the mine. Water-quality data have been collected downstream from the Rio Puerco near Bernardo for 34 years, and the data show that the water at this station is usually more saline than the water in the Rio Moquino and the downstream reach of the Rio Paguate, but still only slightly saline. The Rio Paguate joins the Rio San Jose 5 miles downstream from the Jackpile mining lease, and the Rio San Jose flows into the Rio Puerco about 25 miles southeast of the mouth of the Rio Paguate. The Rio Puerco ultimately flows into the Rio Grande near Bernardo.

Specific-conductance hydrographs were made for four Rio Paguate sampling sites and for three Rio Moquino sampling sites. The hydrographs are not included in this report but are available in the files of the U.S. Geological Survey. The specific conductances were determined in samples collected monthly or less frequently. These hydrographs do not indicate any consistent increasing or decreasing trends for the short periods covered between 1971 and 1980. The fluctuations in specific conductance at each of these sites can be attributed to dilution of the dissolved-solids concentration by large volumes of snowmelt or rainstorm runoff, concentration of dissolved solids by evaporation during periods of low flow, or the flushing of soluble salts into the streamflow during initial storm runoff. It cannot be determined from these graphs that mine-wastewater discharges contributed to these fluctuations.

Specific-conductance hydrographs also were made for samples collected from production wells at the Jackpile mine. The fluctuating specific-conductance measurements may not be necessarily representative of the formation water because of insufficient pumpage to purge the well of water that was standing in the well bore. The fluctuations in the hydrographs are caused by specific-conductance differences generally of about 500 microsiemens per centimeter at 25° Celsius or less. These production-well hydrographs indicate a slight increasing trend for specific conductances beginning in 1978.

Radiochemicals

The mean concentrations of dissolved uranium and dissolved radium-226 in water supplies from the Jackpile mine area and vicinity are listed in table 19. These are arithmetic-mean concentrations at selected surface-water and ground-water sampling sites. Estimated values or values less than analytical detection limits were not used to determine these mean concentrations.

All of the mean concentrations in table 19 are less than the maximum permissible concentration of 5 mg/L for uranium listed in the New Mexico State Ground Water Regulations (New Mexico Water Quality Control Commission, 1982) and of 5 pCi/L (picocuries per liter) for radium-226 listed by the U.S. Environmental Protection Agency (1981). All individual uranium concentrations were less than the permissible limit of 5 mg/L. Although mean concentrations of radium-226 were less than the 5-pCi/L limit, many individual radium-226 concentrations exceeded this limit in the Rio Paguate near the mouth of the Rio Moquino and in the downstream reach of the Rio Paguate. A slight increase in streamflow in this reach is attributed to ground-water seepage, which may be the source of the greater uranium and radium-226 concentrations. The uranium can be expected to remain in solution in oxygen-saturated water, whereas most of the radium-226 will be adsorbed on suspended sediments or the sediments of the channel's bank or bottom because of the alkalinity in the streamflow.

Table 19.--Mean concentrations of uranium and radium-226 in water from the Jackpile mine area and vicinity

Sampling site (fig. 9)	Uranium (milligrams per liter)	Radium-226 (picocuries per liter)
Rio Paguate upstream from mine area	0.008	0.36
Rio Paguate upstream from confluence with Rio Moquino	.160	3.89
Rio Moquino upstream from mine area	.007	.34
Rio Moquino upstream from confluence with Rio Paguate	.051	1.73
Rio Paguate at ford crossing downstream from mine area	.266	4.31
Paguate Reservoir	.210	1.18
Well 4	.005	.54
New shop well	.008	2.19
Old shop well	.112	2.13
Well P10	.0036	.82

The mean concentrations for uranium and radium-226 in water from the wells listed in table 19 also are less than the maximum permissible concentrations; however, the larger concentrations found in the shop wells indicate that the ground water withdrawn from these wells may have flowed from a disturbed orebody or a mined-out area. The use of water from any of the stream sites or wells with the greater uranium or radium-226 concentrations for drinking or other consumptive uses needs to be discouraged. Although mean concentrations in water from these wells are less than maximum permissible limits, they are several orders of magnitude greater than the concentrations found in most natural waters. The concentration of uranium in most natural waters usually is less than 0.01 mg/L, and the concentration of radium-226 usually is less than 0.10 pCi/L. Two other measurements that indicate radiochemicals in solution, gross-alpha and gross-beta radioactivity, had the same concentration patterns in water from the Jackpile mine area and vicinity as described for uranium and radium-226. Uranium isotopes, uranium-238 and uranium-234, and radium-226 account for most of this radioactivity; the radioactive decay products of natural uranium such as thorium-230, lead-210, and radon-222 contribute to the remainder of this radioactivity. Thorium-230 has chemical characteristics similar to those of uranium and would be expected to remain in solution in streamflow, whereas lead-210, like radium-226, is not as soluble. Radon is a gas and would readily escape from solution in an open atmosphere. Radioactive decay of radium-226 produces radon-222 gas, which is almost 100 times more radioactive than an equal weight of radium-226.

Trace Elements

Trace-element data collected from the Jackpile mine area are very limited. Total recoverable concentrations of 18 trace elements in a sample collected on January 24, 1977, from the Rio Paguate at the southern boundary Jackpile mine area are shown in table 20. Trace-element concentrations in water samples from this site may represent cumulative effects of the Jackpile mine area on water quality in the Rio Paguate and Rio Moquino. Also listed in table 20 are the National Primary Drinking Water Regulations limits for trace elements (U.S. Environmental Protection Agency, 1977a) considered to be health risks in water supplies. The other list of trace-element concentration limits in table 20 are those in the New Mexico State Ground Water Regulations (New Mexico Water Quality Control Commission, 1982), which were developed to prevent contamination of ground-water supplies.

Table 20.--Trace-element concentrations in the Rio Paguate at the southern boundary of Jackpile mine

[Concentrations are in micrograms per liter unless otherwise indicated]

Trace element	Total recoverable concentration	Federal limit[1]	State limit[2]
Arsenic (As)	5	50	100
Barium (Ba)	100	1,000	1,000
Cadmium (Cd)	10	10	10
Chromium (Cr)	0	50	50
Fluoride (F), milligrams per liter	.6	[3]1.8	1.6
Lead (Pb)	100	50	50
Mercury (Hg)	.0	2.0	2
Selenium (Se)	8	10	50
Silver (Ag)	10	50	50
Boron (B)	120	--	750
Cobalt (Co)	50	--	50
Copper (Cu)	10	--	1,000
Iron (Fe)	7,500	--	1,000
Manganese (Mn)	180	--	200
Molybdenum (Mo)	2	--	1,000
Vanadium (V)	.3	--	--
Radium (Ra), picocuries per liter	1.7	5.0	30
Uranium (U), milligrams per liter	0.072	--	5

[1] National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1977a)
[2] New Mexico State Ground Water Regulations (New Mexico Water Quality Control Commission, 1982)
[3] For annual average maximum air temperature between 63.9° and 70.6° Fahrenheit

HYDROLOGIC CONDITIONS AFTER RECLAMATION

Part of the pit backfill will saturate after reclamation. Saturation eventually will result from the cessation of pit-water use for road conditioning, a decrease in evaporation of pit water, a possible increase in discharge from bedrock to backfill, and a possible increase in local recharge to the permeable backfill. The water will discharge to streams and to adjacent strata. The water in backfill at the North and South Paguate pits will discharge primarily to the Rio Paguate because only permeable waste rock separates the pits from the stream. Discharge from the Jackpile pit will be to the Jackpile sandstone because the backfill is enclosed by this stratum. Hydraulic heads in the Jackpile sandstone will increase due to saturation of backfill and the end of pumping from underground mines. Pit backfilling is necessary in order to decrease radon formation from the part of the Jackpile sandstone exposed by mining.

Waste piles, which are located primarily on undisturbed areas outside of the pits, are different hydrologically from backfill because the waste piles receive only local recharge. Discharge from the piles may be along the ground surface or into underlying alluvium or bedrock.

Flow through both backfill and waste piles is considered particularly important because: (1) Water flowing through waste rock may contain increased concentrations of dissolved materials due to increased surface area exposed on the rock as the result of mining and due to increased solubility of minerals in the rock as a result of their oxidation; (2) if ponding in the backfill persists, animals using the ponds could injest abnormally large quantities of dissolved materials; and (3) increased concentrations of dissolved materials could enter aquifers and streams.

Flow through Backfill

The Rio Paguate gains water from the alluvium both upstream and downstream from the Paguate pits. A well used for public supply at Paguate village is completed in alluvium of the Rio Paguate and occasionally flows (F. P. Lyford, U.S. Geological Survey, written commun., 1977), indicating discharge to the stream upstream from the mine. Gains in streamflow downstream from the Paguate pits and losses between the pits are described by Hydro-Search, Inc. (written commun., 1979). The present (1980) loss of stream water between the two pits probably is due to infiltration into the permeable backfill underlying the stream. It is, therefore, reasonable to assume that prior to mining, the Rio Paguate was a gaining stream along its length from Paguate village at least to its confluence with the Rio Moquino.

Ground-water levels will approach (or will be similar to) premining levels after reclamation. The downstream part of the backfill underlying the Rio Paguate probably will saturate to stream level. The stream would then be the direct hydraulic control for discharge from backfill in the Paguate pits. Discharge from backfill in the Jackpile pit would be through the Jackpile sandstone, and most of the water probably will enter the alluvium and the Rio Paguate west, and possibly south, of the pit. The level of the Rio Paguate would be the ultimate hydraulic control for water levels in backfill at the Jackpile pit.

Diagrammatic hydrologic models are shown for the South Paguate pit (fig. 10) and the Jackpile pit (fig. 11). Flow through the North Paguate pit would be similar to that for the South Paguate pit except that discharge toward the stream would be southward. The generalized section through the South Paguate pit is from the southernmost edge of the pit (southeast of well P6) to the Rio Paguate upstream from well P4. The generalized section through the Jackpile pit is from the west edge of Gavilan Mesa through well site M18 to the Rio Paguate.

Positions for the water table, level of proposed backfill, and, particularly, the bedrock surface beneath backfill are approximate in figures 10 and 11. Mean thickness of backfill beneath the Rio Paguate is assumed to be about 30 feet. Cross section 12 prepared by the Anaconda Copper Co. (written commun., 1982) shows backfill under the stream to be 40 feet deep. Well site P4 is underlain by 16 feet of fill (Hydro-Search, Inc., written commun., 1979). The contact of the Jackpile sandstone and the underlying mudstone unit of the Brushy Basin Member is at ground level west of the Jackpile pit near the Rio Paguate. The Jackpile sandstone has been removed by erosion near the south end of the Jackpile pit.

Infiltration of backfill will be from runoff, direct precipitation, and discharge from bedrock, particularly the Jackpile sandstone. Discharge will be to the Rio Paguate at the Paguate pits; discharge will be to the Jackpile sandstone, alluvium, and the Rio Paguate at the Jackpile pit. Discharge at the south end of the Jackpile pit also could be through the mudstone unit of the Brushy Basin Member.

Ponding probably will result if backfill in the Paguate pits is below the level of the Rio Paguate adjacent to the pits. Evapotranspiration may be sufficient to prevent long-term ponding if the level of backfill is at stream level, but occasional ponding could occur during periods of minimal evapotranspiration or intense rainfall. Little or no ponding will occur if the backfill is several feet above stream level. The altitude of the stream is about 6,010 feet at the upstream end of the backfill and at about 5,975 feet at the downstream end of the backfill. The height of the water table in backfill will be determined by recharge to the pits and discharge to the Rio Paguate.

Assuming inflow is equal to outflow at the Paguate pits, the general equation for recharge-discharge may be written as:

$$K_j I_j A_j + P = K_b I_b A_b + ET,$$

where:

K is hydraulic conductivity;
I is hydraulic gradient;
A is cross-sectional area perpendicular to flow;
P is water added to the pit by direct precipitation and runoff;
ET is evapotranspiration; and

subscripts "j" refer to the Jackpile sandstone, subscripts "b" refer to the backfill; A linear approximation of the height of the water table is described by the product $I_b D$ for given distances D upgradient from the stream.

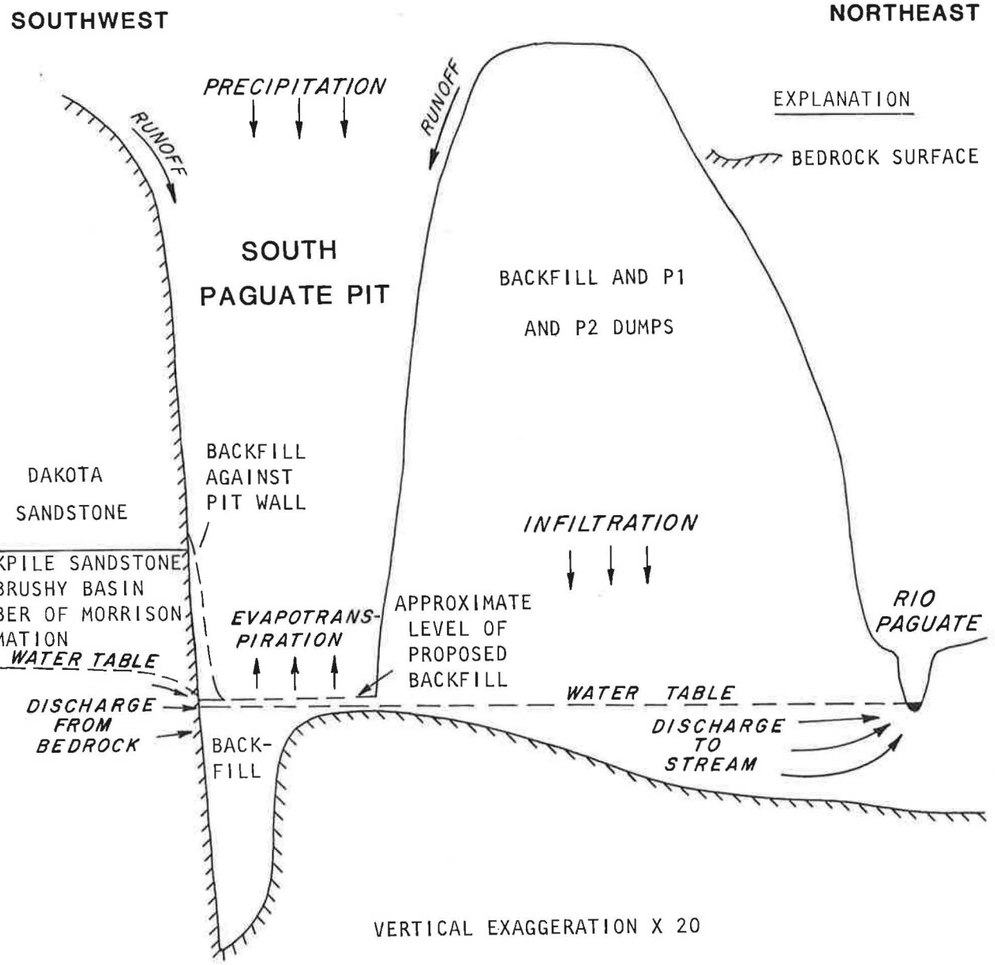


Figure 10.--Diagrammatic hydrologic model of the South Paguate pit.

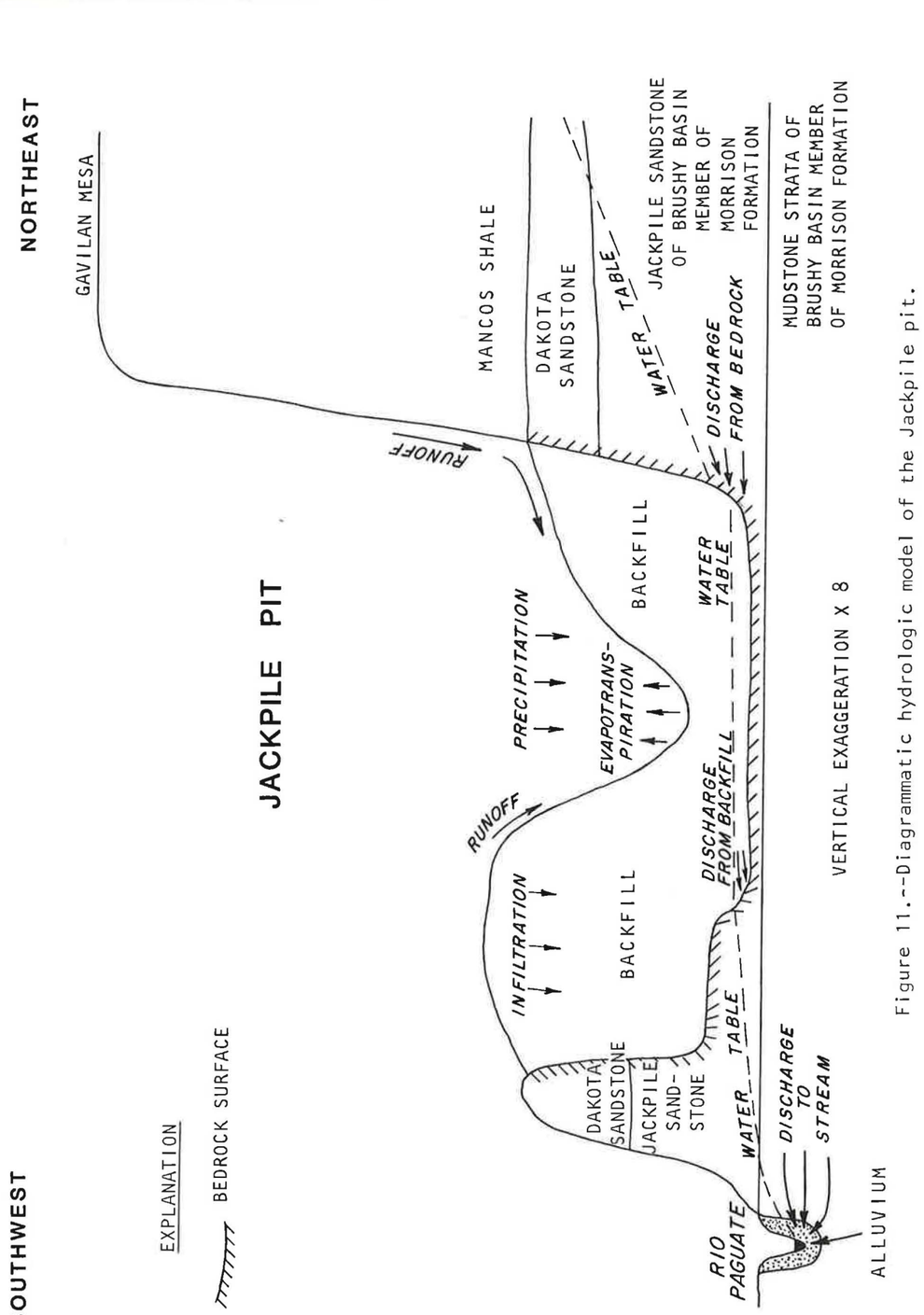


Figure 11.--Diagrammatic hydrologic model of the Jackpile pit.

Values for most factors in the equation above are known or can be reasonably estimated. Little data, however, are available regarding ET. The average ET for the entire Rio Paguate drainage basin may be about 98 percent of precipitation, as described in a previous section. This percentage could be quite different locally, particularly where direct precipitation and runoff from steep pit walls may quickly infiltrate permeable backfill.

The position of the water table in backfill at the Jackpile pit will be controlled by factors described for the Paguate pits, and also by discharge through the Jackpile sandstone, the alluvium, and possibly the mudstone unit in the Brushy Basin Member. Flow may be across at least four boundaries compared to two in the Paguate pits. After reclamation, ground-water levels in backfill will tend to reach equilibrium between hydraulic heads in rocks underlying Gavilan Mesa and the levels of the streams adjacent to the pit. The Rio Moquino is at an altitude of about 5,925 feet west of the Jackpile pit, and the Rio Paguate is at an altitude of about 5,850 feet near the southwest end of the pit.

Flow through Waste Piles

The unnamed valley on the east side of Gavilan Mesa is dry except for short periods after intense rainfall. At least the upper part of the alluvium is, therefore, unsaturated. The waste piles blocking the valley probably also are dry much of the time because no discharge is visible at their downstream end. Water infiltrates the alluvium and waste rock, partly because of occasional ponding at the faces of the piles.

Wetting fronts move more rapidly through fine-grained materials than through coarse-grained materials. Therefore, ponded water at the waste piles may enter the alluvium more rapidly than the waste rock. The volume of water entering alluvium and waste rock and the extent of saturation of the waste rock at the blocked valley probably would be determined best by constructing a flow model of the site.

Numerous waste piles are located outside of valleys and are not part of pit backfill. Recharge to these piles will be from direct precipitation. Reclamation plans call for the piles to be flat topped with terraced sides and berms to decrease erosion. The proposed design might promote infiltration of precipitation.

Assuming waste piles are reclaimed as flat-topped structures with terraces and berms, infiltration of precipitation will be greatest in the basins formed by the structures. Waste piles presently reclaimed have very transmissive vertical channels at the lower parts of the basins. Runoff from adjacent higher areas rapidly infiltrates these vertical channels.

Infiltrating rainfall and runoff may flow through the piles so rapidly that saturation of the waste either does not occur or is short term. The time of water contact with the waste may, therefore, be short, so that solution of minerals from the waste will be minimal if minerals in the waste rock are not greatly soluble. No data, however, are available regarding extent of saturation or water quality in waste piles.

SURFACE-WATER MONITORING CONSIDERATIONS

Sampling sites presently (1980) used for surface-water quality (fig. 9) could continue to be used, except possibly for the one at the "ford crossing." They are properly located for determining water quality at hydrologically important points and probably will monitor changes in quality as water moves through the mine. Four additional locations would be useful for sampling. One of these may be substituted for the ford crossing sampling point. Their location and reasons for sampling them are described below.

The U.S. Geological Survey gaging station at the southern boundary of the mine area, where the Rio Paguate flows beneath the railroad spur, would make a good sampling station for the following reasons: (1) Some water from waste dumps C, D, E, F, and G, and possibly some water from the Jackpile pit, may discharge to the Rio Paguate downstream from the ford crossing sampling point; (2) discharge data from the gaging station may be used to compute a dissolved-constituent load from the mine; and (3) the location is sufficiently far from disturbed areas so that samples from the site may be considered as reflecting most effects from mining activity (except possibly for some flow from the Jackpile pit via alluvium). This sampling point could be substituted for that at the ford crossing.

A sampling point could be established upstream from Paguate Reservoir, north of where swamplike conditions exist due to sedimentation in the reservoir. No data are available regarding flow through alluvium to the Rio Paguate downstream from the mine, but ground-water could discharge to the stream between the southern mine boundary and Paguate Reservoir. The ground-water discharge could change ion concentrations in surface water discharging from the Jackpile mine. The samples presently (1980) collected at the dam of Paguate Reservoir probably reflect considerable evapotranspiration and probably are not representative of freely flowing water to the north of the reservoir.

Two sampling points could be located on the Rio San Jose: one immediately upstream from and one immediately downstream from its confluence with the Rio Paguate. Results of analyses from these samples could be compared to determine the effects of flow from the Rio Paguate on quality of water in the Rio San Jose.

Water-quality samples probably would need to be collected initially about once every 2 months. If trends can be established for a given discharge, sampling frequency might later be extended to once every 3 or 4 months.

Surface-water quality is expected to be much more variable than ground-water quality due to the changes caused by rainfall and evapotranspiration. Care would need to be taken to collect samples at various stream discharges. Minimum concentrations of dissolved ions may be expected during the peak stage or recession of high discharge and maximum concentrations during the initial flush of a storm or during sustained periods of low discharge. Loads of dissolved constituents could be computed by using stream-discharge data.

The same types of analyses as presently established for samples collected from the mine would be useful, that is, analyses for common ions and dissolved solids. Additional analyses are needed, however, for trace elements, gross alpha and gross beta radioactivity, radium-226, and uranium. If significant radioactivity is detected, the radioactive isotopes would need to be identified. Measurement of water temperature, specific conductance, pH, and titration for alkalinity are best done at the sampling site. Duplicate samples may need to be collected occasionally, possibly 1 or 2 per 20 samples collected, and analyzed by a laboratory independent from that normally used in order to compare laboratory results.

GROUND-WATER MONITORING CONSIDERATIONS

Water-quality data collected from existing wells in the Jackpile mine probably will be of limited use because: (1) Many of the wells are not appropriately located; and (2) water-quality data may not be representative at the intended sampling point due to shrinkage of casing cement and resultant leakage of water from upper to lower zones. Cement shrinkage in well annuli may have occurred because several feet of void annular space near the ground surface was observed at some wells. If some existing wells are to be used for monitoring, the wells would need to be pumped until pH and specific conductance of the water have stabilized before samples are collected.

One of two methods may be used to monitor ground-water quality at the Jackpile mine. The first is to determine only the change in quality of ground water that has flowed through the mine. This method is referred to as limited monitoring in this report. This method would neither monitor the sources of possible contaminants nor measure areal changes in water quality. A second method would be to monitor the ground water in such a way that specific sources of possible contaminants are determined and spatial distributions of the possible contaminants are described. This method is referred to as thorough monitoring in this report.

Limited Monitoring

As few as three well sites may be sufficient to monitor only the change in quality of ground water flowing from the open-pit mining area. One well site could be at the southern perimeter of the mine about 2,000 feet east of the stream-gaging station shown on plate 1. One well could be completed in alluvium, and a second well could be completed in the sandstone unit of the Brushy Basin Member at this location. The second site could be at the southeast corner of the mine about 3,000 feet southeast of waste dumps C, D, E, F, and G. Two wells would be needed at this location, and they also could be completed in the alluvium and the Brushy Basin Member. A third site could be at the north end of the mine for the purpose of determining natural water quality. A suitable site probably would be near the Rio Moquino about 1,000 feet north of well M9 (pl. 1). Again, one well completed in alluvium and one well completed in the sandstone unit of the Brushy Basin Member would be useful. In addition, a well could be completed in the sandstone unit of the Brushy Basin Member in Oak Canyon to monitor possible flow from the underground mining area.

Thorough Monitoring

Thorough monitoring would require a greater well density than needed in limited monitoring. Not only would more wells be required, but difficulties can be expected during construction of wells to be completed in backfill.

Monitoring wells would need to be constructed in pit backfill after all planned backfill has been emplaced. Water-quality data from the wells can be used to describe probable maximum concentrations of dissolved substances in water that result from reclamation and that discharge to adjacent rocks and streams. At least one well could be located at each of the following sites: the north side of the South Paguate pit, the south side of the North Paguate pit, and the west side of the Jackpile pit, where the contact of the Jackpile sandstone and mudstone unit of the Brushy Basin Member is below ground level. Ideally, the wells could be positioned at the downgradient end of the backfill. Gradients could be determined by installing several small-diameter wells in each pit and periodically measuring the water levels in these wells. Because pit backfill may not saturate to equilibrium levels for several years, additional monitoring wells may need to be constructed later at the downgradient areas.

Locations of multiple-well sites are described in the following paragraphs. It would be helpful if the wells at any one location were spaced not more than about 30 feet apart in order to observe water-quality changes in aquifers at different depths at essentially the same geographic locations.

Wells for monitoring quality of water discharging from the Jackpile and Paguate pits probably would be needed at the following sites: (1) Three wells west of the Jackpile pit near the Rio Moquino (one well completed in each of the alluvium, the upper part of the Jackpile sandstone, and the base of the Jackpile sandstone); (2) two wells could be about 2,000 feet east of the gaging station and completed as described in the previous section; (3) two wells could be installed at the southeast corner of the mine and completed as described in the previous section; and (4) four wells could be near existing wells M23 and P4 (one well completed in each of the backfill, the alluvium, near the top of the Jackpile sandstone, and near the base of the Jackpile sandstone).

If the water quality in the backfill of the South Paguate and the North Paguate pits is similar, the proposed wells near existing wells M23 and P4 should suffice. If the water quality is different, an additional set of four wells could be constructed north of the Rio Paguate at the south end of the North Paguate pit. These wells would need to be completed in the same strata as described for the proposed wells near M23 and P4.

From an economic viewpoint, waste piles are too numerous to monitor separately. The reclaimed part of "T" dump (pl. 1) could be a representative site. Four wells could be installed at the east side of the dump near the Rio Moquino. One well could be completed in each of the waste rock, the underlying alluvium (if present), the upper part of the Jackpile sandstone, and the base of the Jackpile sandstone.

At least one monitoring well could be installed at the waste piles blocking the valley east of Gavilan Mesa because water occasionally ponds in this area. The well could be located in the valley, immediately downstream from the piles, and completed a few feet below the water table. The water table may be in the alluvium or in the underlying bedrock. Ideally, two other wells could be located at the upstream end of the dumps near the area of ponding. One of the wells could be completed in waste rock, and the other completed a few feet below the water table.

Natural water quality could be determined by installing three wells about 1,000 feet north of existing well M9. One well could be completed in alluvium, one in the Jackpile sandstone, and one in the sandstone unit of the Brushy Basin Member.

Sampling Frequency and Types of Analyses

Initial sampling frequency could be about once every 3 months. If trends can be established after several sampling periods, the frequency could be changed to about twice yearly. If samples are collected two times a year, one sampling period could be in late winter and the other in late fall. Local recharge in the mine area probably is least in winter and greatest in summer.

Types of analyses could be the same as presently done for samples from the mine, as explained in the section regarding proposed surface-water monitoring. Temperature, specific conductance, pH, and titration for alkalinity would best be measured at the sampling site. Duplicate samples probably would need to be collected at least once a year for the purpose of comparing laboratory results.

SUMMARY AND CONCLUSIONS

About 2,656 acres of land are to be reclaimed at the Jackpile mine, which is located on the Pueblo of Laguna in northwestern New Mexico. Uranium was surface mined from the Jackpile sandstone (economic usage) in the Brushy Basin Member of the Morrison Formation from 1953 to late 1980. Reclamation plans probably will include partial backfilling of three open pits to decrease radon formation and modifying the shape of waste-rock piles located outside of the pits.

The pits are as much as 200 to 300 feet below the adjacent ground surface and have an area of 1,015 acres. Piles of waste rock are as much as 200 feet in height; most are about 50 to 75 feet high. Thirty-two piles of waste rock cover 1,266 acres. Reclamation probably will include making waste piles flat-topped in order to resemble the mesas in the area. Terraces and berms are to be constructed on the sides of the piles to decrease erosion.

Primary hydrologic concerns are that oxidation and the large surface area of rock fragments in backfill and waste piles may cause greater than normal dissolution of rock minerals, including radionuclides and trace elements, by water flowing through the waste. Virtually no data exist regarding quality of water passing through the waste rock. Water from waste rock will discharge to adjacent streams and adjacent aquifers, principally the alluvium and the Jackpile sandstone.

The topography of the Laguna area is mountainous with numerous mesas. Altitudes range from 11,300 feet at Mount Taylor to 5,700 feet on the Rio San Jose south of the Jackpile mine. The climate is arid, with mean annual precipitation of 9.5 inches. Surface-water evaporation is about 76 inches per year as measured by the pan-evaporation method. Evapotranspiration losses are estimated to be about 98 percent of precipitation.

The Rio Paguate flows through the Jackpile mine, and the Rio Moquino is tributary to the Rio Paguate in the northern part of the mine. The Rio Paguate flows into Paguate Reservoir about 3 miles downstream from the southern mine boundary, then enters the Rio San Jose about 1.0 mile south of where the Rio Paguate enters the reservoir. Mean daily discharge of the Rio Paguate for water years 1977-80 was 1.19 cubic feet per second at the south end of the mine, about 50 percent of which was base flow. Peak discharge during large floods ranges from about 1,520 cubic feet per second once every 5 years to about 10,500 cubic feet per second once every 500 years, as estimated by the basin-characteristics method.

The Rio Paguate flows over waste rock between the North and South Paguate pits. Present (1980) loss of stream water between the Paguate pits is caused by infiltration into the backfill, pumpage from underground mines, evapotranspiration, and lowering of the water table in the area due to loss of water from pits by pumpage for road conditioning.

Ponding may occur where waste dumps block an arroyo at the east side of the Jackpile mine. Maximum depth of ponded water is estimated to be 4 feet for a flood flow of 1 day at a recurrence interval of 50 years. Depths probably are less than 2 feet for most flow periods and recurrence intervals. Water from the pond will infiltrate underlying alluvium and waste rock at the upstream end of the dumps.

Sediment has nearly filled the Paguate Reservoir since construction of the dam in 1940. Sediment yield due to mining is less than about 1 percent of total sediment yield in the basin, and sediment deposited in the reservoir due to mining is estimated to be less than 0.24 acre-foot per year. The sediment contribution resulting from mining is small because the externally draining area of the mine constitutes only about 1 percent of the 107-square-mile drainage area in the Rio Paguate basin upstream from the southern boundary of the mine.

The recharge rate in the Rio Paguate drainage basin is estimated to be about 0.1 inch per year, based on the sum of base flow and underflow through alluvium. Rates may vary locally with altitude, ground slope, rock type, and distribution of alluvium and eolian deposits. Recharge to rocks in the Jackpile mine is from high areas on the flanks of Mount Taylor to the west and probably from Mesa Chivato to the north. Some recharge may occur locally in the mine. Regional ground-water flow is southward toward the Rio San Jose and eastward toward the Rio Puerco. Most of the local flow in alluvium and in the Jackpile sandstone discharges to mine pits, to underground mines presently being dewatered, and to the Rio Paguate and Rio Moquino. Some ground water may flow from the mine via alluvial and eolian deposits and from rocks in the Brushy Basin Member.

The hydraulic conductivity is about 23 feet per day for the alluvium and about 0.3 foot per day for the Jackpile sandstone and for a sandstone bed in the underlying part of the Brushy Basin Member. Mudstone beds approximately 100 feet thick separate the deeper sandstone from the Jackpile sandstone. Minimal hydraulic connection between the two sandstone strata indicates that the mudstone unit is the lower boundary of the hydrologic system in the mine area. Hydraulic-head differences between the two sandstone beds, however, indicate downward flow of some water from the Jackpile sandstone.

Water in the Rio Moquino is a mixed-ion type, with dissolved solids ranging from about 1,600 mg/L upstream from the mine to about 1,900 mg/L at its mouth. Water in the Rio Paguate upstream from the confluence with the Rio Moquino is a sodium bicarbonate type, with dissolved solids ranging from 575 to 700 mg/L. Downstream from the confluence of the streams, the water in the Rio Paguate is of the same type as in the Rio Moquino, with dissolved solids of about 2,000 mg/L. Mean concentrations of dissolved solids in samples of ground water range from 900 to 1,500 mg/L.

Concentrations of uranium, radium-226, and other trace elements generally were less than permissible limits established in national drinking-water regulations or New Mexico ground-water regulations. Trace elements that could pose water-quality problems because of their association with uranium ores are lead, selenium, iron, manganese, molybdenum, vanadium, radium, and uranium.

Mean concentrations of uranium and radium-226 increase through the mine area at various surface-water sampling sites. None of the mean concentrations exceeded permissible concentrations for public use. No individual stream-water samples collected upstream from the mine contained radium-226 concentrations in excess of permissible limits. However, many individual radium-226 concentrations in the Rio Paguate from near the mouth of the Rio Moquino and along the downstream reach of the Rio Paguate exceeded the permissible concentration of radium-226 for public drinking-water supplies. Concentrations in surface water apparently are changed by ground-water inflow near the confluence of the two streams.

Part of the backfill in the pits will become saturated after reclamation. The water will discharge to adjacent strata and to streams. Discharge from the Paguate pits primarily will be from backfill in the pits to permeable waste rock and to the Rio Paguate. Most discharge from the Jackpile pit probably will be from backfill to the Jackpile sandstone, then to alluvium and to the Rio Paguate. Some discharge from the Jackpile pit could be to strata underlying the Jackpile sandstone. Previous studies determined that the backfill has a hydraulic conductivity of 190 feet per day at well M24.

The depth to the water table in pit backfill will be partly controlled by the water level in the Rio Paguate adjacent to the pits. Other factors controlling the altitude of the water table will be the recharge rate to the backfill and the hydraulic conductivity of the backfill, alluvium, Jackpile sandstone, and mudstone unit of the Brushy Basin Member. Computer flow models of the pits could be made to estimate post-reclamation water levels in the backfill for given conditions.

Waste piles are different hydrologically from backfill, in that they receive only local recharge. Recharge principally will be from direct precipitation on most piles. The basins formed by berms constructed around terraces will promote infiltration. Recharge to the upstream part of the backfill blocking the arroyo east of Gavilan Mesa will be caused by temporary ponding at the faces of the dumps. Virtually no information, however, exists regarding extent of saturation in waste piles. The waste rock may be permeable enough so that saturation is limited and of short duration. Discharge from the piles may be to ground surface or to underlying alluvium and bedrock. Computer flow models could be made of a typical waste pile and of the waste piles blocking the arroyo east of Gavilan Mesa.

After reclamation, most of the shallow ground water probably will discharge to the natural stream channels draining the mine area. The remaining ground water probably will flow to the south and east, where erosion has removed the northwest-dipping Jackpile sandstone from the valleys.

Four surface-water monitoring stations could be established in addition to those presently sampled. Their locations could be as follows: at the gaging station on the Rio Paguate at the south end of the mine area, on the Rio Paguate immediately north of Paguate Reservoir, on the Rio San Jose immediately upstream from the Rio Paguate, and on the Rio San Jose immediately downstream from the Rio Paguate. The present sampling station at the ford crossing could be discontinued.

Surface-water-quality samples could be collected about once every 2 months and at different stream discharges. If water quality can be mathematically related to given discharges, sampling frequency could later be changed to once every 3 or 4 months. Loads of dissolved constituents could be computed using stream-discharge and water-quality data collected at the gaging station. Duplicate sampling could be done at least once a year to compare results from different laboratories. Types of analyses that probably would be needed are common ions, dissolved solids, trace elements, gross alpha radioactivity, gross beta radioactivity, and uranium. Measurements of water temperature, specific conductance, pH, and alkalinity could be made at the sampling sites.

Quality of ground water could be monitored as: (1) "Limited monitoring," in which only the change in water quality is determined as the ground water flows through the mine; or (2) "thorough monitoring," in which specific sources of possible contaminants are determined, and spatial distributions of the possible contaminants are described. As few as three well sites are needed for limited monitoring; one could be located at the northern part of the mine for determining natural water quality and one each at the south and southeast ends of the mine to determine changes in water quality (which would likely be due to mining). Paired wells could be completed at each site as follows: one in alluvium, and one in the sandstone strata below the mudstone unit in the Brushy Basin Member. Many more well sites would be required for thorough monitoring, and they are described in the text of this report.

Ground-water-quality samples probably need to be collected about once every 3 months initially. If trends can be established, the frequency could be changed to twice yearly. Types of analyses, field measurements at the sampling sites, and duplicate sampling could be the same as described above for surface water.

REFERENCES

Borland, J. P., 1970, A proposed streamflow-data program for New Mexico: U.S. Geological Survey open-file report, 71 p.

Boulton, N. S., 1963, Analysis of data from non-equilibrium pumping tests allowing for delayed yield from storage: Institute of Civil Engineers, Proceedings, London , v. 26, p. 315-320.

Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopulos, I. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

Daniel, J. F., Cable, L. W., and Wolf, R. J., 1970, Ground water-surface water relation during periods of overland flow: U.S. Geological Survey Professional Paper 700-B, p. B219-B223.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2nd ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Moench, R. H., and Schlee, J. S., 1967, Geology and uranium deposits of the Laguna district, New Mexico: U.S. Geological Survey Professional Paper 519, 117 p.

New Mexico State Engineer Office, 1956, Climatological summary, New Mexico precipitation 1849-1954: New Mexico State Engineer Office Technical Report 6, 407 p.

New Mexico Water Quality Control Commission, 1982, New Mexico Water Quality Control Commission regulations as amended through January 29, 1982: New Mexico Health and Environment Department WQCC 81-2, 36 p.

Papadopulos, I. S., and Cooper, H. H., Jr., 1967, Drawdown in a well of large diameter: Water Resources Research, v. 3, no. 1, p. 241-244.

Risser, D. W., and Lyford, F. P., 1983, Water resources on the Pueblo of Laguna, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 83-4038, 308 p.

Schlee, J. S., and Moench, R. H., 1963a, Geologic map of the Moquino quadrangle, New Mexico: U.S. Geological Survey Geologic Map GQ-209, scale 1:24,000.

____ 1963b, Geologic map of the Mesita quadrangle, New Mexico: U.S. Geological Survey Geologic Map GQ-210, scale 1:24,000.

Scott, A. G., and Kunkler, J. L., 1976, Flood discharges of streams in New Mexico as related channel geometry: U.S. Geological Survey Open-File Report 76-414, 29 p.

Shown, L. M., 1970, Evaluation of a method for estimating sediment yield: U.S. Geological Survey Professional Paper 700-B, p. B245-B249.

Stiff, H. A., Jr., 1951, Interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. III, no. 10, p. 15-16.

REFERENCES - Concluded

Theis, C. V., 1935, The relation between the lowering of a piezometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophysical Union Transactions, v. 16, pt. 2, p. 519-524.

Thomas, R. P., and Gold, R. L., 1982, Techniques for estimating flood discharge for unregulated streams: U.S. Geological Survey Water-Resources Investigations Report 82-24, 42 p.

U.S. Department of Commerce, 1967, Map of precipitation frequency: USCOMM-ESSA-DC R5271, prepared by Special Studies Branch, Office of Hydrology, Weather Bureau Environmental Science Service Administration.

U.S. Environmental Protection Agency, 1972, Water quality criteria 1972: Ecological Research series, EPA-R3-73.003, 594 p.

_____1977a, National interim primary drinking water regulations: EPA-570/9-76-003, 159 p.

_____1977b, National secondary drinking water regulations: Federal Register, v. 42, no. 62, pt. 1, p. 17143-17147.

_____1981, Proposed disposal standards for inactive uranium processing sites: Federal Register, v. 42, no. 62, pt. 1, p. 17143-17147.

SUPPLEMENTAL INFORMATION

Table 21.--Mean monthly and mean annual discharge for Paguate Creek near Laguna, New Mexico

[All values are in cubic feet per second]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1937	-	-	-	-	-	1.45	1.77	0.73	0.61	0.66	0.77	0.70	-
1938	0.78	0.98	1.15	1.16	1.07	1.18	1.24	1.21	.91	.82	.35	1.03	0.99
1939	.76	.92	1.04	1.06	1.04	1.58	2.09	.85	.48	.93	.88	.62	1.02
1940	.85	1.10	1.22	1.16	1.62	1.18	1.14	.92	.47	.80	.76	1.06	1.02
1941	.84	1.67	1.42	1.18	1.59	5.92	12.6	14.7	1.51	.71	.93	2.42	3.80

Table 22.--Mean monthly and mean annual discharge for Rio Paguate downstream from Jackpile mine near Laguna, New Mexico

[All values are in cubic feet per second]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1976	-	-	-	-	-	-	1.21	1.05	0.48	0.38	4.18	0.79	-
1977	0.67	1.07	1.15	1.66	1.68	1.66	1.53	2.00	.54	.69	1.71	.340	1.48
1978	.47	.61	.95	1.55	2.09	1.34	.81	.98	.37	.28	3.33	.20	1.08
1979	.22	1.59	.80	1.99	2.66	3.57	1.36	1.13	.56	.16	1.26	.76	1.33
1980	.30	.69	.65	1.59	1.77	1.80	.82	.29	.12	.047	.095	2.28	.87

Table 23.--Classification of water based on dissolved-solids concentrations

The U.S. Geological Survey has assigned terms for freshwater and degrees of salinity based on concentrations of dissolved solids as follows:

Classification	Dissolved-solids concentration (milligrams per liter)
Fresh	Less than 1,000
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000 - 35,000
Briny	More than 35,000

☆ U.S. GOVERNMENT PRINTING OFFICE: 1985—676-631/45002 REGION NO. 8

HYDROGEOLOGIC RELATIONSHIPS
RABBIT EAR AND P-10 HOLDING PONDS
JACKPILE-PAGUATE MINE
VALENCIA COUNTY, NEW MEXICO

Hydro-Search, Inc.
CONSULTING HYDROLOGISTS-GEOLOGISTS
Reno • Denver

HYDROGEOLOGIC RELATIONSHIPS
RABBIT EAR AND P-10 HOLDING PONDS
JACKPILE-PAGUATE MINE
VALENCIA COUNTY, NEW MEXICO

June 15, 1979

Prepared for

The Anaconda Company
New Mexico Operations
Mineral Resources Group
Grants, New Mexico 87020

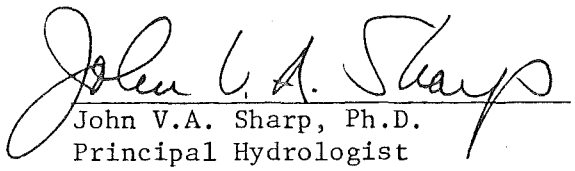
Project No. 1100

Hydro - Search, Inc.
Consulting Hydrologists - Geologists

333 Flint Street
Reno, Nevada 89501

777 S. Wadsworth Blvd.
Denver, Colorado 80226

Submitted by:



John V.A. Sharp, Ph.D.
Principal Hydrologist

TABLE OF CONTENTS

TABLES

FIGURES

1.0 FINDINGS

1. The water of the P-10 ponds was pumped from the P-10 underground workings which are in the Jackpile sandstone. The ponds occupied excavations in the Jackpile sandstone. The pond water was a sodium-sulfate-bicarbonate type of slightly over 1,000 mg/l total dissolved solids. The pond water was indistinguishable on a chemical basis from the adjacent Jackpile aquifer water. Concentrations of uranium and Ra-226 in the pond water exceeded those of the ground water.

2. The water of the Rabbit Ear pond was pumped from open pits in the Jackpile sandstone to the southwest. The pond occupied an excavation in the Jackpile sandstone. The pond water was a sodium-sulfate type of nearly 5,000 mg/l total dissolved solids. The pond water was unlike the sodium-sulfate-bicarbonate water of the adjacent Jackpile aquifer. The difference probably was due at least in part to concentration by evaporation in the pond. Concentrations of uranium and Ra-226 in the pond water exceeded those of the ground water.

3. The water surfaces of the ponds were above the regional hydraulic potential surface of the Jackpile aquifer, raising the possibility that pond water could have discharged by downward seepage to the Jackpile aquifer.

4. No evidence exists that such seepage discharge occurred. Evidence against seepage discharge includes:

   a. the ponds maintained a positive head relative to the aquifer, indicating a difficult hydraulic connection that was not favorable for downward movement of water;

   b. lack of appearance of pond water at nearby down gradient test wells; and

   c. lack of recharge mounds in the adjacent aquifer.

   The lack of seepage discharge is consistent with both the occurrence of fine-grained clayey material which covered the bottom of the ponds and the relatively impervious nature of the Jackpile aquifer.

5. The regional ground-water flow system of the Jackpile aquifer discharges to the Rio Paguate and Rio Moquino in the vicinity of the confluence of the streams. The gain water is high in chemical and radiological constituents relative to the receiving stream waters. The source of the poor quality of the discharged ground water is not the P-10 ponds and Rabbit Ear pond, but is some other factor or source of water which is not completely understood at this time.

6. As of spring 1979, Rabbit Ear pond has been drained and no longer exists, the western P-10 pond has been backfilled, and the eastern pond is being backfilled.

2.0 INTRODUCTION

This report presents results of a detailed field and office investigation of the ground- and surface water hydrology of the Jackpile-Paguate Mine of The Anaconda Company, located seven miles northeast of Laguna, Valencia County, New Mexico (Figure 1). The investigation was undertaken during the period March 1977 through March 1979.

The purposes of the investigation were to determine if seepage discharge has occurred from the unlined Rabbit Ear and P-10 holding ponds in the mine and, if seepage discharge has occurred, the possible resulting effects upon the ground- and surface water systems. The water held in the ponds was pumped from the mine workings. Evidence cited later in this report indicates that inflow from the regional ground-water system did not contribute to the pond water.

The current investigation included two phases. Phase I consisted of review of published and Anaconda geologic and hydrologic data and evaluation of the adequacy of these data to accomplish the purposes of the investigation. The data base was found to be insufficient, and a combination

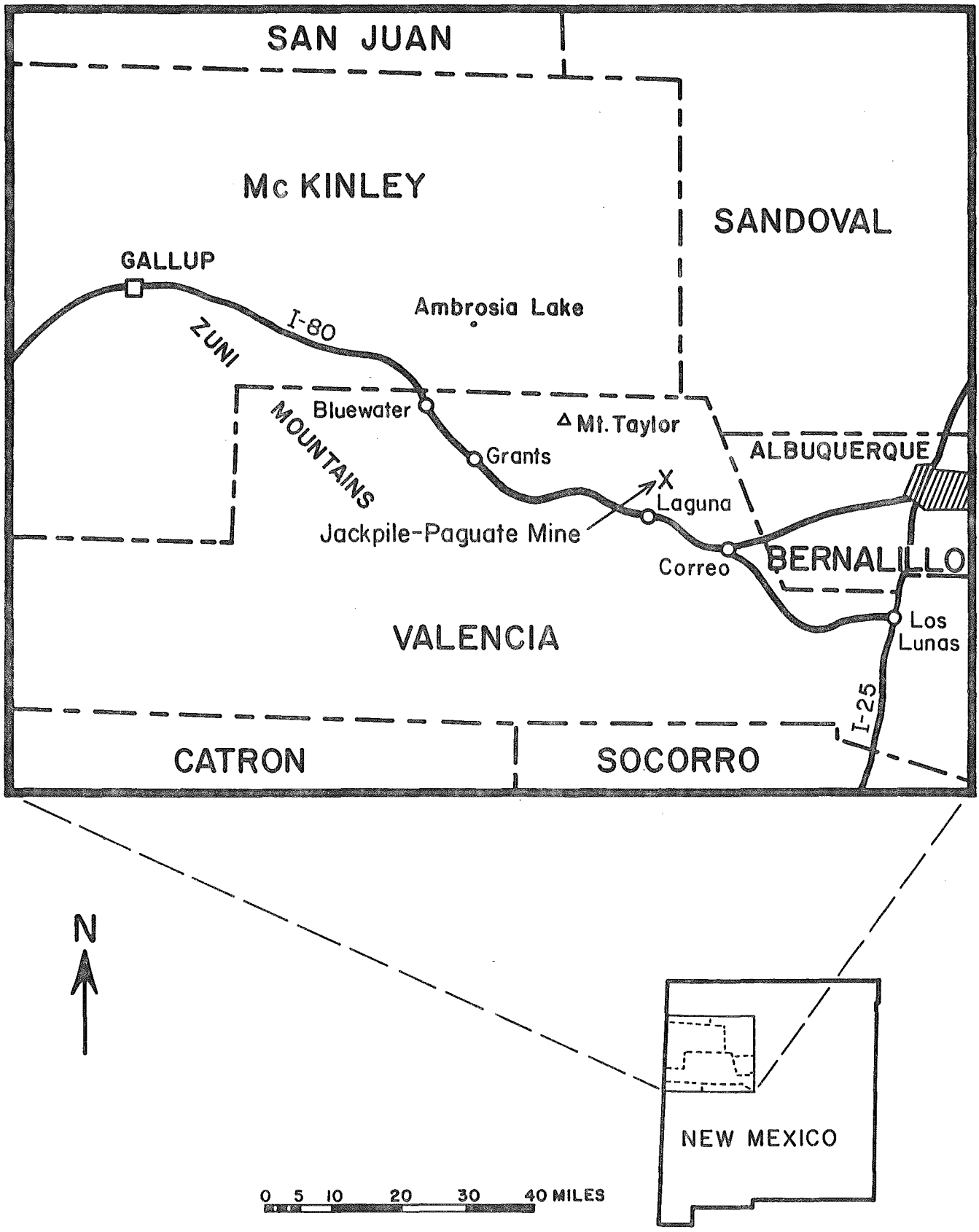


Figure 1. Location Map of Jackpile-Paguate Mine, The Anaconda Company.

field-office program, Phase II, was instituted to obtain the necessary additional data. The field and laboratory work which was performed during the period December 1977 through March 1979 included: 1) construction of test wells for acquisition of geological information, measurement of ground-water elevations, and sampling/analysis of ground water; and 2) determination of water chemistry, flows, and chemical fluxes of the two perennial streams which traverse the mine site, the Rio Paguate and Rio Moquino.

Results of the Phase II program are incorporated into the text of this report.

Personnel of Hydro-Search, Inc. who participated in this work include John V.A. Sharp, principal hydrologist and project manager, Thomas K. Wheeler and Lee C. Atkinson, senior hydrogeologists, and Forrest L. Fox, hydrogeologist.

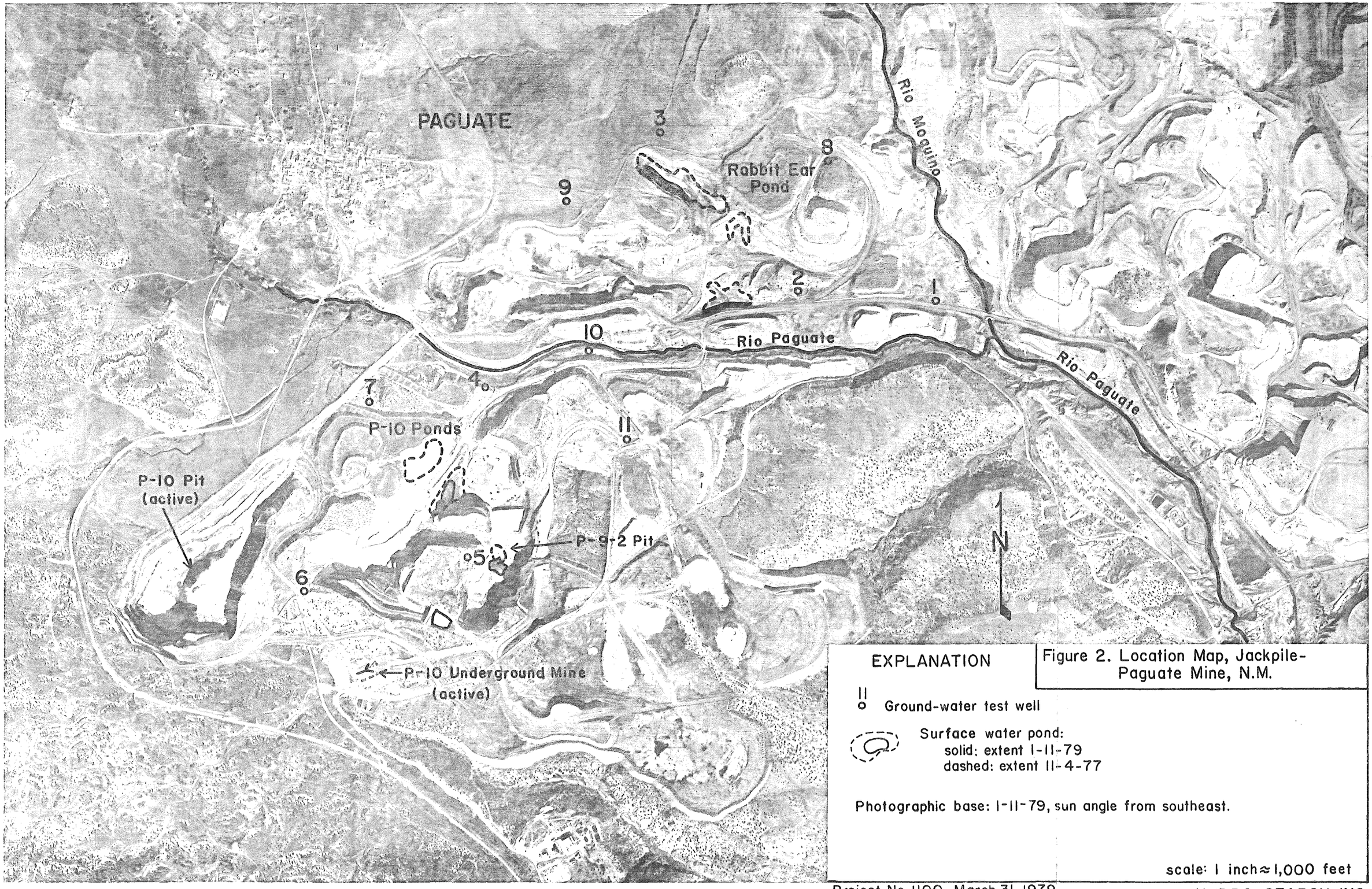
3.0 HYDROGEOLOGY

3.1 GROUND-WATER RELATIONSHIPS

3.1.1 Geology

The uranium mineralization of the Jackpile-Paguate Mine occurs in a sandstone unit at the top of the Morrison Formation. This sandstone has received the informal designation, Jackpile sandstone, and has been described as a yellowish-gray to white, fine- to medium-grained, poorly to moderately well sorted, friable and kaolinitic sandstone with sparse, thin beds of grayish-green mudstone (Moench and Schlee, 1967). The Jackpile sandstone underlies the area of the mine where it averages about 160 feet thick.

The Jackpile underlies the Quaternary eolian and alluvial deposits of unconsolidated sand and silt along the courses of Rio Paguate and Rio Moquino (Figure 2; Schlee and Moench, 1963a). The Jackpile underlies the mesas of the mine area, now partially removed by stripping, which are comprised of Dakota Sandstone, about 50 feet thick (Schlee and Moench, 1963a), and overlying lowermost Mancos Shale. The Jackpile is underlain by the Brushy Basin Member of the Morrison Formation. This unit is predominantly greenish-gray bentonitic mudstone with occasional thin beds of clayey sandstone. Thickness exceeds several hundred feet in the vicinity of the mine (Schlee and Moench, 1963a).



EXPLANATION

11 o Ground-water test well

Surface water pond:
solid: extent 1-11-79
dashed: extent 11-4-77

Photographic base: 1-11-79, sun angle from southeast.

scale: 1 inch ≈ 1,000 feet

Figure 2. Location Map, Jackpile-Paguate Mine, N.M.

Project No. 1100 March 31, 1979

HYDRO-SEARCH, INC.
Reno · Denver 350002852

The stratigraphic units described above dip about one degree to the north-northwest. Faulting is virtually absent. Occasional diabase dikes and sills occur in the mine area (Schlee and Moench, 1963a).

3.1.2 Ground-Water Hydrology

Ground-water relationships of the Jackpile sandstone are of importance for the following reasons:

1. The mine workings and included uranium mineralization and accompanying related radionuclides (e.g., radium) occur in the Jackpile sandstone.

2. The Jackpile sandstone contains ground water and locally yields water to open pits and underground workings. The holding ponds (Rabbit Ear, P-10) for the produced water were located on and within the Jackpile.

3. The Jackpile sandstone underlies Rio Paguate and Rio Moquino, and probably is in hydraulic connection with these streams via the Quaternary sand and silt deposits.

4. The streams receive water by discharge from the Jackpile sandstone. If relatively poor quality water in storage in the ponds has seeped to the Jackpile, such discharged water could ultimately enter the streams and could result in degradation of water quality.

The Brushy Basin Member forms a continuous impervious boundary beneath the Jackpile sandstone. As a consequence, the ground-water system of the Jackpile can be considered to be isolated from underlying aquifers. The overlying Dakota Sandstone does not contain significant ground water in the mine area because of its relatively high topographic position. The sandstones

of the Dakota probably are water-saturated northwest and west of the mine where this unit dips beneath the apparent regional ground-water potentiometric surface. The Dakota contains dark shales, particularly in the lower part, and these shales probably act as confining layers to the Jackpile aquifer in the northern and western portions of the mine area where the Jackpile is buried beneath the younger units.

In summary, the Jackpile acts as a hydraulically isolated, tabular aquifer which contains ground water under confined conditions in the northern and western portions of the mine. Ground water is unconfined on the east and southeast. Stripping and underground mining of the Jackpile on the west and northwest have resulted in local conversion of the original confined condition to an unconfined condition and some removal and dewatering of the aquifer. On the extreme east and southeast of the mine area, the Jackpile is in a relatively high topographic position and under current (and probably under pre-mining) conditions the Jackpile does not contain a significant quantity of ground water.

The interested reader should consult the geologic maps of the Moquino Quadrangle (Schlee and Moench, 1963a) and adjoining quadrangles (Mesita - Schlee and Moench, 1963b; Seboyeta - Moench, 1963a; Laguna - Moench, 1963b) for information regarding geologic relationships both in the immediate mine area prior to mining and on a regional basis.

3.2 CHARACTERISTICS OF HOLDING PONDS

In recent years, four significant bodies of standing water have existed in the western portion of the mine (Figure 2). Rabbit Ear pond on the north was instituted in 1972-73 as a holding facility for water removed from workings in the Paguate portion of the mine. A smaller pond also was maintained about 1,000 feet south of the Rabbit Ear pond. To our knowledge, mine drainage water was not discharged to either of these ponds during the period November 1977 through March 1979. For the past few years water pumped out of the P-10 underground workings has been held in the P-10 ponds (Figure 2). Water from the holding ponds has been used for dust suppression.

Recently, the volume of water in these ponds has decreased drastically (Figure 2). This is attributable to several factors, including: 1) increase in dust suppression activities, 2) backfill of the western P-10 pond with waste rock, 3) diversion of water pumped from the P-10 underground workings to a new pond which is about 1,000 feet to the northeast of the entrance to the underground workings, and 4) dewatering of the Rabbit Ear and adjacent pond to allow exploration drilling in these areas.

A small amount of standing water occurs in the bottom of P-9-2 pit (Figure 2). This is water pumped from nearby inactive underground workings.

The bottom of the ponds is covered by a layer of clayey material several inches to one foot thick.

3.2.1 Rabbit Ear Pond

At its maximum extent, this pond covered slightly more than six acres with a maximum depth of on the order of 20 feet. Thus, a reasonable estimate of maximum water in storage is about 65 acre feet. As of spring 1979, this pond no longer exists. Hydrologic information, such as surface area-depth-volume relationships and long-term rates of input and output of water, does not exist.

Rabbit Ear pond was sampled for water chemistry in December 1977 when the pond was near maximum stage. The water was a sodium-sulfate type of about 4,900 mg/l total dissolved solids (TDS) by calculation (Table 1). Concentrations of uranium and Ra-226 were 3.1 mg/l and 26. pCi/l, respectively (Table 2).

Prior analyses in 1975 and 1974 (Table 3) show a similar chemical type of water, but at a substantially lower concentration. Radiological constituents showed similar concentrations in 1977 as compared to 1975 (Tables 2 and 3).

The small pond between Rabbit Ear pond and Rio Paguate on the south at its maximum covered about three acres (Figure 2). This pond no longer exists. In contrast to the nearby Rabbit Ear pond, this pond showed in December 1977 a magnesium-sodium-sulfate type of water with relatively low TDS of about 2,600 mg/l (Table 1). Concentrations of uranium and Ra-226 were 2.2 mg/l

Table 1. Major Dissolved Chemical Constituents, Holding Ponds and Test Wells, Jackpile-Paguate Mine, New Mexico.

	NMEID Standards	Rabbit Ear Pond 12-21-77	Pond South of Rabbit Ear Pond 12-21-77	P-10 Ponds Composite 12-20-77	Test Well #1 12-20-77	Test Well #2 12-20-77
pH	6 to 9	8.2	8.1	8.3	8.1	7.9
TDS (calc.)	1,000	4,888*	2,613*	1,219*	1,210*	961
Elec.Cond., field		5,780	3,260	1,970	1,890	1,520
Elec.Cond., lab		6,240	3,300	2,000	1,820	1,490
HCO_3^-		167.5	200	410	505	365
$CO_3^=$		12	6	12	---	---
Cl^-	250	54.5	44	24	24	21
$SO_4^=$	600	3,195*	1,700*	510	540	430
Na^+		1,040	360	430	130	125
K^+		32	30	6	14	8
Ca^{++}		285	125	18	175	140
Mg^{++}		187.5	250	9.5	59	41
SiO_2		< 0.1	< 0.1	7.8	20	17

Note: Analyses are in mg/l except pH which is in units and electrical conductivity which is in μmhos/cm @25° C.
Analyses by The Industrial Laboratories Company, Denver, Colorado.
*Concentration exceeds standard.

Table 1. (Continued)

	Test Well #3 12-20-77	Test Well #4 12-21-77	Test Well #5 12-21-77	Test Well #6 12-21-77	Test Well #7 12-21-77
pH	8.7	8.1	8.2	8.0	8.1
TDS (calc.)	875	1,149*	1,044*	1,103*	1,027*
Elec.Cond., field	1,300	1,720	1,620	1,680	1,580
Elec.Cond., lab	1,360	1,780	1,610	1,670	1,600
HCO_3^-	340	435	425	445	405
$CO_3^=$	36	---	12	---	---
Cl^-	18	28	17	21	24
$SO_4^=$	320	450	420	415	415
Na^+	310	430	360	410	360
K^+	3	5	4	10	4
Ca^{++}	4.9	16	9.8	16	11
Mg^{++}	7.7	< 1	1.8	3	4
SiO_2	8.2	6.6	10	9.4	9.8

Table 1. (Continued)

	Test Well #8 9-16-78	Test Well #9 9-16-78	Test Well #10 9-15-78	Test Well #11 9-16-78
pH	8.2	8.1	7.4	8.0
TDS (calc.)	896	1,348*	992	1,577*
Elec.Cond., field				
Elec.Cond., lab	1,080	1,700	1,280	1,890
HCO_3^-	365	420	260	370
$CO_3^=$	---	---	---	---
Cl^-	14	17	21	17
$SO_4^=$	380	645*	515	840*
Na^+	280	450	150	450
K^+	3	6	5	7
Ca^{++}	21	9.8	110	49
Mg^{++}	11	5.7	50	20
SiO_2	7.5	7.5	13	12
	F^- = 1.0	F^- = 1.0	F = 1.0	F = 1.4
	PO_4^{-3} <0.1	PO_4^{-3} <0.1	PO_4^{-3} <0.1	PO_4^{-3} <0.1

Table 2. Dissolved Radiological Constituents, Holding Ponds and Test Wells, Jackpile-Paguate Mine, New Mexico.

	Date	Uranium, mg/l	Radium-226, pCi/l
NMEID Standard		5.	30. (in combination with Ra-228)
Rabbit Ear Pond	12-21-77	3.1±0.15	26.±1.
Pond south of Rabbit Ear Pond	12-21-77	2.2±0.10	39.±2.
P-10 Ponds composite	12-21-77	1.2±0.06	86.±4.
Test Well # 1	12-20-77	0.053±0.004	1.62±0.08
Test Well # 2	12-20-77	0.16±0.007	20.±1.
Test Well # 3	12-20-77	0.009±0.006	3.2±0.2
Test Well # 4	12-21-77	0.87±0.04	29.±1.
Test Well # 5	12-21-77	0.012±0.004	22.±1.
Test Well # 6	12-21-77	0.038±0.001	6.4±0.7
Test Well # 7	12-21-77	< 0.006	1.77±0.09
Test Well # 8	9-16-78	0.043*	1.62±0.09
Test Well # 9	9-16-78	0.007*	0.70±0.06
Test Well #10	9-15-78	0.25*	0.43±0.05
Test Well #11	9-16-78	0.062*	2.5±0.1

Note: Analyses are on filtered samples. Results represent concentrations in solution.

Uncertainty is one standard deviation due to counting statistics. Detection limits are one standard deviation.

*Analysis agency - CDM/ACCU-LABS, Wheat Ridge, Colorado. All other analyses by LFE Environmental Analysis Laboratories, Richmond, California.

Table 3. Selected Previous Chemical and Radiological Analyses, Holding Ponds, Jackpile-Paguate Mine, New Mexico.

	NMEID Standards	Rabbit Ear Pond		P-10 Pond	
		5-8-75[1]	11-74[2]	5-8-75[1]	11-74[2]
pH	6 to 9	8.2	8.6	8.6	8.05
TDS (reported)	1000	2,507*	1,536*	1,030*	
TDS (calc.)		2,067*		1,002*	
Elec. Cond.		2,200		1,325	
HCO_3^-		193		328	
$CO_3^=$		---		14	
Cl^-	250	19	23	18	14
$SO_4^=$	600	1,243*	1,030*	422	352
F^-	1.6		.92		0.840
NO_3^-	45 (10 mg/l as N)	2	< .45	2	4.05
Na^+		550		360	
K^+					
Ca^{++}		96		16	
Mg^{++}		62		9	
As	0.1		< 0.01		< 0.01
Ba	1.0		< 0.001		0.104
Cd	0.01		< 0.001		< 0.001
Cr	0.05		0.001		0.001
CN	0.2		0.06		0.220*
Pb	0.05		< 0.001		0.033
Hg	0.002		0.0008		0.0001
Se	0.05		< 0.100		< 0.100
Ag	0.05		< 0.001		< 0.001
Cu	1.0		0.002		0.005
Fe	1.0	< 0.1	0.290		
Mn	0.2	< 0.1	< 0.001		0.145
Zn	10.0		0.05		0.010
B	0.75		0.410		0.360
Mo	1.0		0.018		0.390
Ni	0.2		< 0.001		< 0.001
Uranium, mg/l	5.	3.01		0.972	
Ra-226, pCi/l (in combination with Ra-228)	30.	19.9±1.7		92.6±3.8	

Note: Analyses are in mg/l except where noted, pH which is in units, and electrical conductivity which is in µmhos/cm @25° C.

[1]The Anaconda Company.

[2]Dames and Moore, 1976, Table 4.2-9.

*Concentration exceeds standard.

and 39. pCi/l, respectively (Table 2).

3.2.2 P-10 Ponds

When sampled in December 1977, these ponds showed a surface area of about five acres (Figure 2). At that time the water was a sodium-sulfate-bicarbonate type of low TDS of about 1,200 mg/l (Table 1). Concentrations of uranium and Ra-226 were 1.2 mg/l and 86. pCi/l, respectively (Table 2).

Prior analyses in 1975 and 1974 (Table 3) show a similar chemical type of water, but at a slightly lower concentration. Radiological constituents showed similar concentrations in 1977 as compared to 1975 (Tables 2 and 3).

As indicated previously, the western pond has been backfilled with waste rock and the eastern pond currently (spring 1979) has been reduced to about one acre in surface area in the process of being backfilled with waste rock. Hydrologic information, such as surface area-depth-volume relationships and long-term rates of input and output of water, does not exist.

3.3 RELATIONSHIP OF HOLDING POND WATER TO THE JACKPILE GROUND-WATER BODY

3.3.1 Hydrogeologic Test Wells

To accomplish the purpose of this investigation it was necessary to determine the hydraulic potential (pressure) surface and water chemistry of the Jackpile aquifer in the vicinity of the holding ponds in the western

Table 4. Ground-Water Test Wells, Jackpile-Paguate Mine, N.M., 1977-78.

Test Well	Date	Depth, feet	Generalized Geologic Log	Cased Depth, feet	Perforated Interval, feet	Comment
1	12-12-77	115	0- 16':fill 16- 55':alluvium 55-110':Jmj 110-115':Jmb	115	2-115	
2	12-12-77	156	0- 20':Kd 20-146':Jmj 146-156':Jmb	156	35-156	
3	12-13-77	325	0-178':Kd & Km 178-318':Jmj 318-325':Jmb	325	60-325	
4	12-16-77	225	0- 16':fill 16- 46':alluvium 46-219':Jmj 219-225':Jmb	186*	86-186	
5	12-14-77	278	0-130':Kd & Km 130-270':Jmj 270-278':Jmb	278	67-278	
6	12-15-77	340	0-173':Kd & Km 173-306':Jmj 306-340':Jmb	340	89-329	
7	12-15-77	268	0-140':Kd & Km 140-255':Jmj 255-268':Jmb	268	50-257	
8	9-13-78	249	0- 97':Kd & Km 97-240':Jmj 240-249':Jmb	249	149-249	
9	9-12-78	330	0-182':Kd & Km 182-320':Jmj 320-330':Jmb	330	210-310	
10	9-14-78	262	0- 82':alluvium 82-262':Jmj 262-265':Jmb	55*	20- 55	Not open to Jmj.
11	9-11-78	260	0-110':fill 110-125':Kd 125-245':Jmj 245-260':Jmb	260	100-260	

Note: *Hole caved and could not be cased to total depth.
Km = Mancos Shale, Kd = Dakota Sandstone, Jmj = Jackpile sandstone, Jmb = Brushy Basin member of the Morrison Formation.

Table 5. Water Level Elevations in Ground-Water Test Wells, Jackpile Aquifer, Jackpile-Paguate Mine, 1977-79.

Test Well	Ground Level Elevation, feet	Dec. 21, 1977		Sept. 14-16, 1978		March 28, 1979	
		Depth to Water, feet	Elev. of Water Level, feet	Depth to Water, feet	Elev. of Water Level, feet	Depth to Water, feet	Elev. of Water Level, feet
1	5943.42	43.30	5900.12	43.50	5899.92	43.70	5899.72
2	5973.65	50.55	5923.10	52.47	5921.18	51.86	5921.79
3	6072.87	144.83	5928.04	146.99	5925.88	148.44	5924.43
4	6008.47	44.77	5963.70	45.44	5963.03	52.51	5955.96
5	6124.29	154.36	5969.93	149.01	5975.28	152.33	5971.96
6	6237.88	254.33	5983.55	244.29	5993.59	246.26	5991.62
7	6109.26	130.35	5978.91	123.15	5986.11	126.50	5982.76
8	6042.00			120.11	5921.89	119.52	5922.48
9	6087.10			165.40	5921.70	165.90	5921.20
10*	6007.47			39.28	5968.19	37.25	5970.22
11	6100.25			143.37	5956.88	140.66	5959.59

Note: Ground level elevations by The Anaconda Company.
*Casing open to alluvium and not to Jackpile aquifer (see Table 4).

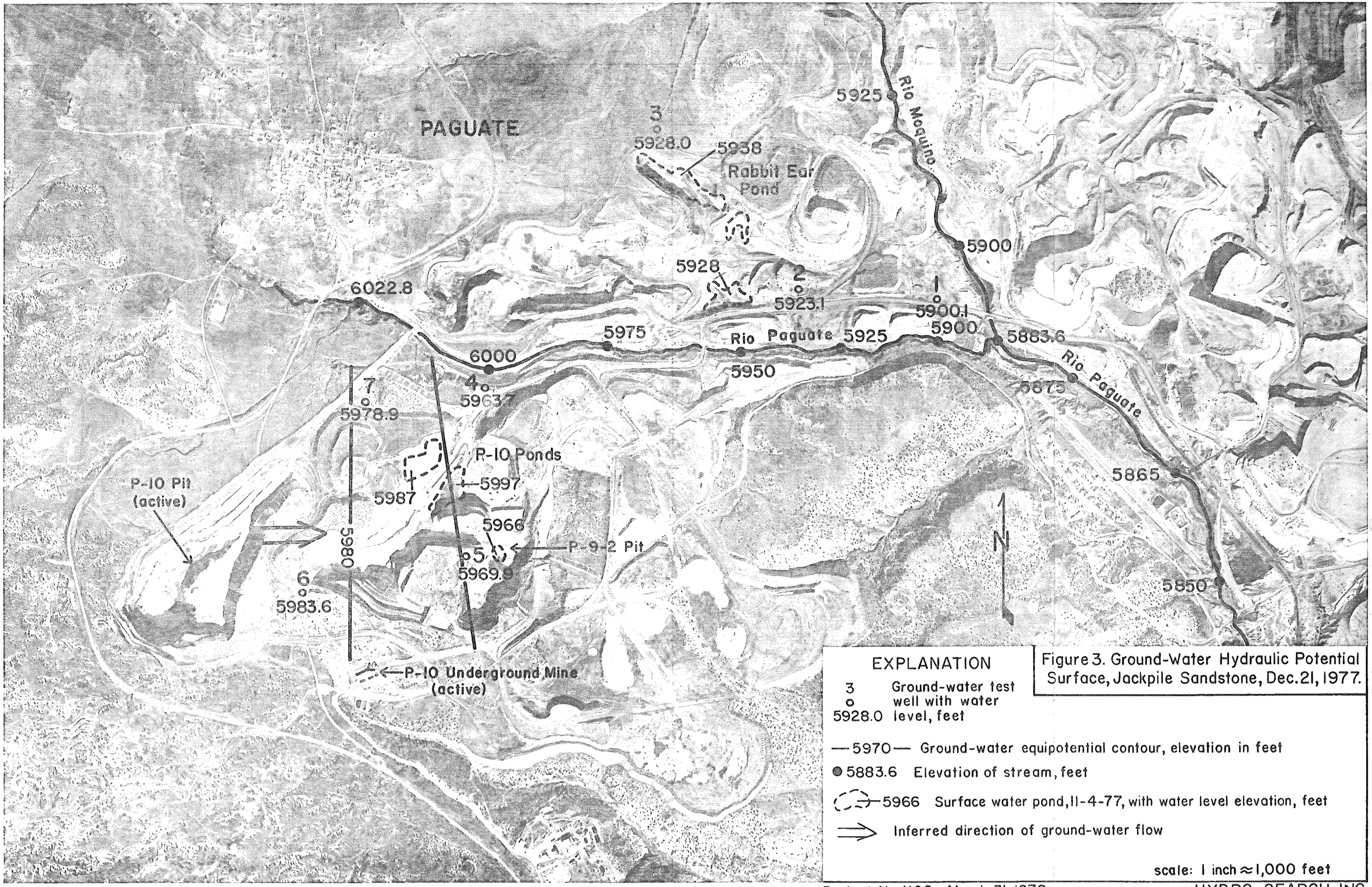
portion of the mine. No water wells completed solely in the Jackpile aquifer exist in this area (Dames and Moore, 1976, Table 4.2-6). Consequently, it was necessary to construct eleven test wells of 5-inch diameter by rotary air percussion method at selected locations. These wells range in depth from 115 to 340 feet, were cased with 2-inch PVC, and with one exception (test well #10) the casing is perforated opposite water-saturated Jackpile sandstone (Table 4).

3.3.2 Movement of Ground Water

Table 5 gives water level elevations in the eleven test wells at three different times during 1977-79. Ground-water hydraulic potential surfaces for that part of the mine west of the confluence of Rio Paguate and Rio Moquino as derived from these data are shown in Figures 3 through 5.

South of Rio Paguate through the area of the P-10 ponds ground water in the Jackpile sandstone flows to the east and northeast. The hydraulic gradient increases from 0.01 on the west to 0.03 on the east near the confluence. North of Rio Paguate ground water moves in from the north. Ground water which flows through the area of Rabbit Ear pond moves to the southeast. The ground-water flows converge and discharge to both Rio Paguate and Rio Moquino at and for a short distance above the confluence.

West of elevation 5925 feet the Rio Paguate flows at a higher elevation



EXPLANATION

3 o 5928.0 — Ground-water test well with water level, feet

—5970— Ground-water equipotential contour, elevation in feet

● 5883.6 Elevation of stream, feet

5966 Surface water pond, 11-4-77, with water level elevation, feet

Inferred direction of ground-water flow

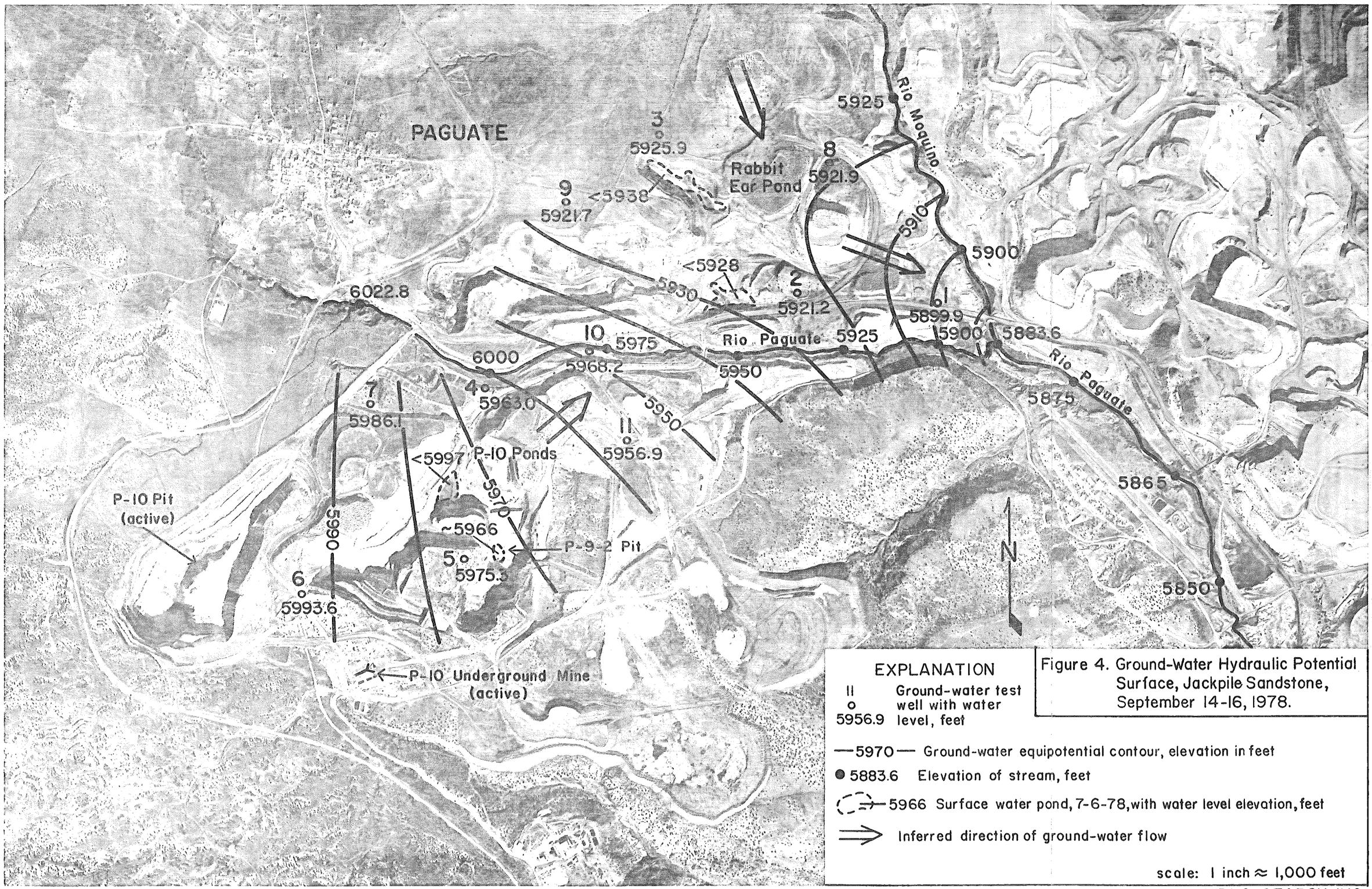
scale: 1 inch ≈ 1,000 feet

Figure 3. Ground-Water Hydraulic Potential Surface, Jackpile Sandstone, Dec. 21, 1977.

Project No. 1100 March 31, 1979

HYDRO-SEARCH, INC.
Reno · Denver

350002866



EXPLANATION

II	Ground-water test well with water level, feet
o 5956.9	

—5970— Ground-water equipotential contour, elevation in feet

● 5883.6 Elevation of stream, feet

5966 Surface water pond, 7-6-78, with water level elevation, feet

Inferred direction of ground-water flow

scale: 1 inch ≈ 1,000 feet

Figure 4. Ground-Water Hydraulic Potential Surface, Jackpile Sandstone, September 14-16, 1978.

Project No. 1100 March 31, 1979

HYDRO-SEARCH, INC.
Reno · Denver 350002867

PAGUATE

3 o 5924.4

Rabbit Ear Pond

8 o 5922.5

5925

Rio Moquino

9 o 5921.2

5930

5910

5900

6022.8

2 o 5921.8

1 o 5899.7

10 5975

5970.2

Rio Paguate

5925

5900

5883.6

6000

5950

Rio Paguate

5875

7 o 5982.8

5970

4 o 5956.0

5950

11 o 5959.6

P-10 Ponds

5865

P-10 Pit (active)

5990

~5966

P-9-2 Pit

5 o 5972.0

6 o 5991.6

N

5850

P-10 Underground Mine (active)

EXPLANATION

3 o 5924.4 Ground-water test well with water level, feet

—5970— Ground-water equipotential contour, elevation in feet

● 5883.6 Elevation of stream, feet

5966 Surface water pond, 1-11-79, with water level elevation, feet

Inferred direction of ground-water flow

scale: 1 inch ≈ 1,000 feet

Figure 5. Ground-Water Hydraulic Potential Surface, Jackpile Sandstone, March 28, 1979.

Project No. 1100 March 31, 1979

HYDRO-SEARCH INC.
Reno · Denver 350002868

than the potentiometric surface of the Jackpile, suggesting that the Rio Paguate recharges the alluvium and perhaps the underlying Jackpile along this reach. This is confirmed by the observation (Section 5.0) that Rio Paguate loses water along this reach.

Test well #10 is completed and the casing is perforated in the stream alluvium (Table 4). Water levels in this well are intermediate between those of Rio Paguate and the underlying Jackpile. This is consistent with the influent (losing) nature of Rio Paguate.

When they were active, Rabbit Ear pond and the P-10 ponds were at a higher elevation than the potentiometric surface of the Jackpile aquifer (Figures 3 and 4). This raises the possibility of seepage discharge of pond water to the aquifer. However, evidence cited later in this report indicates that this did not occur. The pond south of Rabbit Ear pond was at about the elevation of the potentiometric surface of the Jackpile ground-water body and may have been in hydraulic continuity with the aquifer. In this case, the pond would have acted as a local discharge area on the Jackpile ground-water flow system where water was removed by evapotranspiration.

3.3.3 Water Chemistry

Chemical Constituents

Discussion and interpretation of major dissolved chemical constituents of water are facilitated by the use of trilinear diagrams wherein percentages,

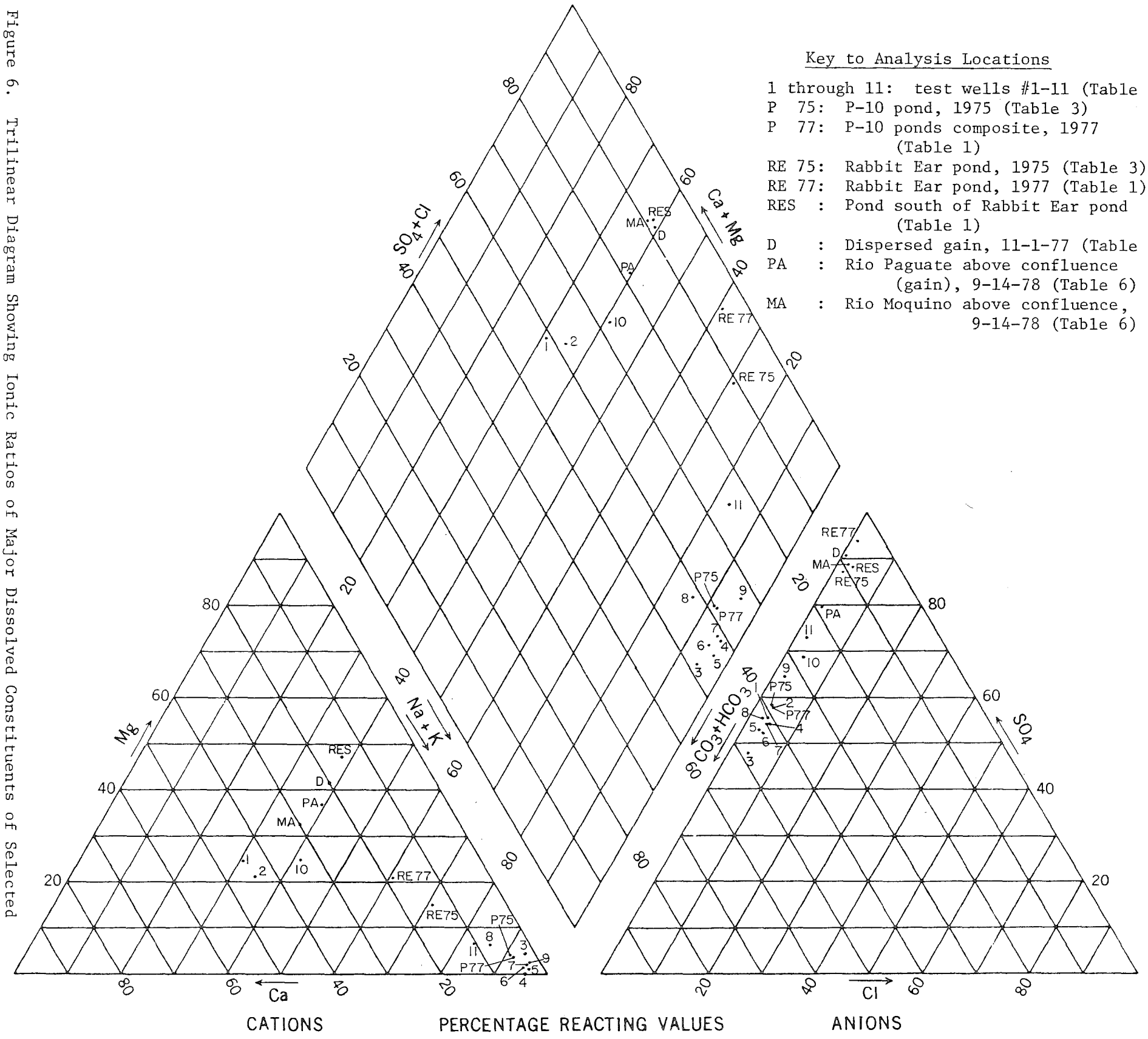
calculated as ionic ratios, of the major ions are plotted as points in three fields - cation, anion, and combined cation and anion (Figure 6). This approach is used in the following discussion.

Two chemical types of ground water occur. The most widespread is a sodium-sulfate-bicarbonate type which occurs in the areas around the P-10 ponds (test wells #4-7, 11) and the Rabbit Ear pond (test wells #3, 8, 9) (Table 1). The trilinear diagram shows a well-defined clustering of point plots of these waters in each of the three fields. This type of water ranges in total dissolved solids (calculated) (TDS) from 875 mg/1 to 1,577 mg/1 with an average of 1,127 mg/1 and a standard deviation of ± 235 mg/1.

A calcium-sulfate-bicarbonate type of water occurs at test wells #1 and 2 and in test well #10 which is completed in the alluvium along Rio Paguate. The trilinear diagram shows a well-defined clustering of point plots. The clustering coincides with that of the sodium-sulfate-bicarbonate waters in the anion field, but a well-defined differentiation between the two types occurs in the cation and combined fields. TDS of the three calcium-sulfate-bicarbonate waters range from 961 mg/1 to 1,210 mg/1 with an average of 1,054 mg/1.

The above ranges and averages are considered to be indicative of the natural concentrations of major chemical constituents as unaffected by mining acti-

Figure 6. Trilinear Diagram Showing Ionic Ratios of Major Dissolved Constituents of Selected Waters, Jackpile-Paguate Mine, New Mexico.



Key to Analysis Locations

1 through 11: test wells #1-11 (Table 1)
P 75: P-10 pond, 1975 (Table 3)
P 77: P-10 ponds composite, 1977 (Table 1)
RE 75: Rabbit Ear pond, 1975 (Table 3)
RE 77: Rabbit Ear pond, 1977 (Table 1)
RES : Pond south of Rabbit Ear pond (Table 1)
D : Dispersed gain, 11-1-77 (Table 6)
PA : Rio Paguate above confluence (gain), 9-14-78 (Table 6)
MA : Rio Moquino above confluence, 9-14-78 (Table 6)

factors which are responsible for the difference in cation composition, sodium vs. calcium, of these otherwise similar Jackpile ground waters are unknown.

Radiological Constituents

The eight sodium-sulfate-bicarbonate waters show the following statistics for uranium and Ra-226 (Table 2).

	Range	Average
Uranium, mg/1	<0.006 - 0.87	0.13
Ra-226, pCi/1	0.7 - 29.	8.4

Statistics for the three calcium-sulfate-bicarbonate waters are as follows:

	Range	Average
Uranium, mg/1	0.053 - 0.25	0.15
Ra-226, pCi/1	0.43 - 20.	7.4

The above ranges and averages are indicative of the natural concentrations of radiological constituents as unaffected by mining activities.

3.3.4 Interpretation

Water of the P-10 ponds, both in 1977 (Table 1) and 1974-75 (Table 3), is indistinguishable from the sodium-sulfate-bicarbonate water of the surrounding Jackpile aquifer. TDS of 1,219 mg/1 (1977) and 1,002 mg/1 (1975) for the P-10 ponds is close to the average of 1,127 mg/1 for the eight well waters.

The 1977 and 1975 analyses plot within the defined clusters on the trilinear diagram (Figure 6), and negligible change occurred in ionic composition and overall concentration from 1975 to 1977.

The P-10 waters show high concentrations of uranium and Ra-226 (Tables 2 and 3) relative to the average (see above) for the sodium-sulfate-bicarbonate waters. The relatively elevated concentrations of these radiological constituents could be either of natural origin and related to the specific source of this water in the mineralized Jackpile sandstone of the P-10 underground workings or due to exposure of this water to uranium mineralization either during removal from the workings or in geological materials in the ponds.

The water levels of the P-10 ponds were above the potentiometric surface of the Jackpile aquifer (Figures 3 and 4). Although fine-grained material covers the bottom of the ponds, downward seepage discharge of pond water to the Jackpile aquifer could have occurred. However, even if such discharge did occur, degradation of the aquifer (and ultimately Rio Paguate into which the aquifer discharges) would not have resulted from the standpoint of major dissolved chemical constituents. This is because the pond water was unaltered ground water and seepage discharge of this water would not have resulted in a decrease in overall quality of the receiving ground water.

Similarly, seepage discharge from the P-10 ponds would have increased concentrations of radiological constituents in the Jackpile aquifer to greater than natural levels (see above) only if the radiological constituents in the pond water were due to mining activities and not of natural origin. Test well #11 which is about 2,000 feet down hydraulic gradient to the east from the P-10 ponds shows concentrations of radiological constituents below average for the Jackpile aquifer (Table 3). This suggests that seepage discharge and subsequent lateral migration of seepage water either did not occur or are restricted in extent and degree.

The water of Rabbit Ear pond is a distinctive, relatively concentrated sodium-sulfate type that increased markedly in concentration from 1974-75 (Table 3) to 1977 (Table 1). The ionic ratio of sodium decreased over that period as both calcium and magnesium increased. The input water to Rabbit Ear pond was from pits due south of test well #9. However, the water of Rabbit Ear pond is of higher concentration and different compositional type than the water of test well #9 (sodium-sulfate-bicarbonate). The distinctive characteristics of the Rabbit Ear pond water may be attributable to evaporation concentration of an input sodium-sulfate-bicarbonate water from the pits to the south. This possibility is supported by the location of the 1975 plots of the Rabbit Ear water in all three fields of the trilinear diagram (Figure 6) on a straight line (an "evaporation" line) between the input sodium-sulfate-bicarbonate water and the plots of the evaporation concentrated 1977 Rabbit Ear water.

The water level of the Rabbit Ear pond was above the potentiometric surface of the Jackpile aquifer (Figures 3 and 4). Although fine-grained material covers the bottom of the pond, downward seepage discharge of pond water to the Jackpile aquifer could have occurred. If such discharge did occur, the aquifer waters would have been degraded from standpoints of both major chemical and radiological (Tables 2 and 3) constituents. Three test wells (#1, 2, and 8) occur down hydraulic gradient to the east and southeast from Rabbit Ear pond. These waters do not show either partial admixing or complete appearance of Rabbit Ear pond type water. This suggests that seepage discharge and subsequent lateral migration of seepage waters either did not occur or are restricted in extent and degree.

Chemistry of the water in the pond about 1,000 feet south of Rabbit Ear pond is of interest. This water was a distinctive, relatively intermediate concentration magnesium-sodium-sulfate type (Table 1) which is not found elsewhere in the mine area. As discussed on page 23, this pond may have been in direct hydraulic continuity with the Jackpile ground-water body but the source and causes of the distinctive chemical composition of this water are unknown. Possibilities include evaporative concentration in the pond, reaction of ground water moving in from the southwest or along the channel fill of Rio Paguate with geologic materials, or a localized body of relatively poor quality water moving in from the southwest. It is unlikely that this water is related to or caused by possible seepage discharge from

the P-10 ponds or Rabbit Ear pond. A direct connection or relationship to the mining activities is not evident. This water does not show up in test wells #1 and 2 which are down hydraulic gradient to the east from this pond.

350002876

4.0 SURFACE WATER HYDROLOGY

The U.S. Geological Survey, Water Resources Division, Albuquerque found a gain in flow of Rio Paguate and Rio Moquino through the mine area of an average of about 95 gpm. This was for three flow discharge surveys that were conducted during the winter of 1974-75 (Dames and Moore, 1976, Table 4.2-1). Information developed by our investigation indicates that the Jackpile ground-water system discharges water to these streams (Section 3.3.2). The area of stream gain is at the confluence and for a short distance, 500 to 1,000 feet, upstream on both streams. We looked for visible ground-water seeps upon several occasions but did not find any. This leads us to conclude that the ground-water discharge is by dispersed seepage along the stream beds. Stream discharge measurements and flow characteristics determined by our investigation (see below) confirm the increase in flow and, in addition, show that Rio Paguate in the western portion of the mine is a losing stream.

An increase in concentrations of dissolved chemical species and radiological constituents in stream waters through the mine area has been noted by several groups. For example, the water monitoring program of The Anaconda Company for May 8, 1975 gave the following results.

	TDS Calculated, mg/l	Uranium, mg/l
Rio Moquino, upstream on north	1,179	0.0022
Rio Paguate, upstream on west	484	0.0009
Rio Paguate, downstream at road ford	1,317	0.0586

Similar increases through the mine area were found by the Environmental Protection Agency (1975, pp. 33, 72) for a variety of radiological and major and minor chemical constituents on February 28, 1975.

Dames and Moore (1976, pp. 4.2-14 through 4.2-19) conducted two surveys of uranium concentrations in the Rio Moquino and Rio Paguate during August and September 1975. Results indicate that concentrations increased on Rio Paguate through a reach from a point immediately west of station 5900 (Figure 7) to about 1,000 feet below the confluence and on Rio Moquino through a reach from a point about midway between stations 5900 and 5925 (Figure 7) to the confluence.

As part of the current investigation, Hydro-Search, Inc. conducted two flow and chemical surveys of the Rio Paguate-Rio Moquino system. The purpose was to investigate the apparent discharge of ground water from the Jackpile sandstone to the streams, the possible effect of this discharge on water

Figure 7. Stream Surveys, Jackpile - Paguate Mine, N.M.

EXPLANATION

3 ○ Ground-water test well

Stream, solid - flow (9-14-78) dotted - no flow (9-14-78)

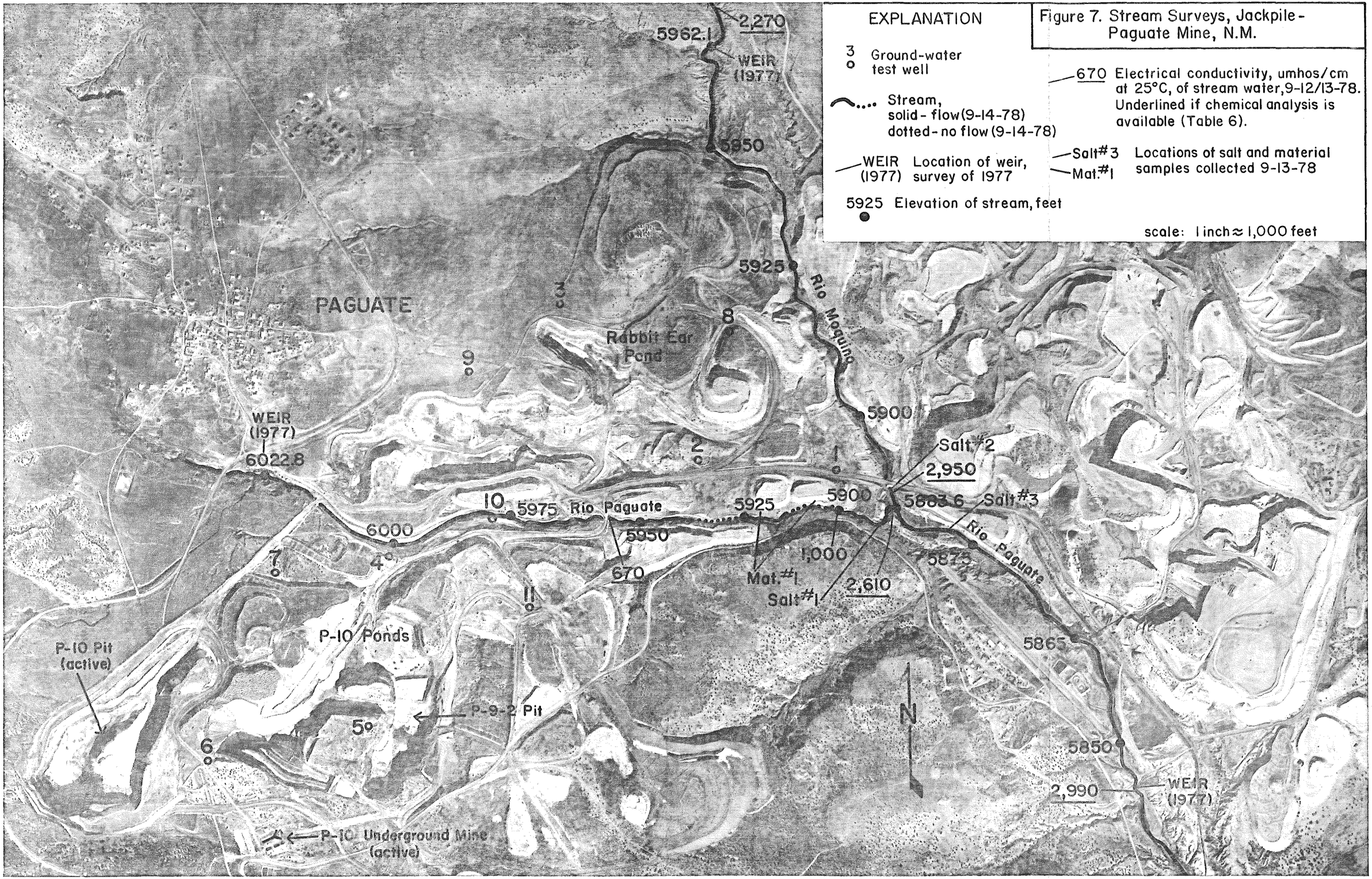
WEIR (1977) Location of weir, survey of 1977

5925 Elevation of stream, feet

670 Electrical conductivity, umhos/cm at 25°C, of stream water, 9-12/13-78. Underlined if chemical analysis is available (Table 6).

Salt #3 / Mat. #1 Locations of salt and material samples collected 9-13-78

scale: 1 inch ≈ 1,000 feet



Project No. 1100 March 31, 1979

HYDRO-SEARCH INC.
Reno · Denver

350002879

quality of the streams, and any relationships which might occur between water quality of the streams and waters of the P-10 ponds and Rabbit Ear pond.

4.1 STREAM SURVEY OF OCTOBER-NOVEMBER 1977

A stream survey was performed October 29 through November 1, 1977. Weirs were installed on Rio Paguate at the western boundary of the mine and at the road ford downstream on the southeast and on Rio Moquino at the northern boundary of the mine (Figure 7). Average net gain through the mine for a series of five measurements on October 29 and 31 and November 1 was 43 gpm (Table 6). Water samples were taken on November 1 and results are given in Table 6 (major chemical constituents), Table 7 (minor constituents), and Table 8 (radiological constituents).

Calculations based upon chemical flux (= concentration x volumetric flow rate) and volumetric flow rates yield calculated apparent concentrations for individual chemical and radiological species for the 43 gpm of dispersed inflow water (Tables 6 through 8). The dispersed inflow water is a magnesium-sodium-sulfate type very similar in chemical composition to the water of the pond south of Rabbit Ear pond (Figure 6). However, the dispersed inflow is of somewhat higher concentration than the pond water (4,890 mg/1 vs. 2,613 mg/1 TDS).

Table 6. Major Dissolved Chemical Constituents, Rio Paguate and Rio Moquino, Jackpile-Paguate Mine, New Mexico.

	NMEID standards	Rio Paguate west weir 11-1-77	Rio Moquino north weir 11-1-77	Rio Paguate south weir 11-1-77	Calculated dispersed inflow through mine area 11-1-77
pH	6 to 9	8.7	8.2	8.3	
TDS (calc.)	1,000	657	1,664*	2,013*	4,890*
Elec.Cond., field					
Elec.Cond., lab		880	1,970	2,400	
HCO_3^-		325	220	260	328
$CO_3^=$		24	12	18	33
Cl^-	250	6.6	16	16	27
$SO_4^=$	600	205	1,000*	1,220*	3,222*
F^-	1.6	0.4	0.6	0.7	1.4
NO_3^-	45 (10 mg/l as N)	0.4	0.3	0.9	3.7
Na^+		150	290	330	689
K^+		6	14	16	35
Ca^{++}		85	150	165	314
Mg^{++}		5.8	65	110	397
SiO_2		14	7.6	8.7	6.4
Flow		51 gpm	156 gpm	250 gpm	43 gpm (calculated)

Note: All analyses in mg/l except pH which is in units and electrical conductivity which is in µmhos/cm @ 25° C.
Analyses by The Industrial Laboratories Company, Denver, Colorado.
*Concentration exceeds standard.

Table 6. (Continued)

	Rio Paguate @ culvert in western mine area 9-14-78	Rio Paguate above confluence with Rio Moquino 9-14-78	Rio Moquino @ falls on north 9-14-78	Rio Moquino above confluence with Rio Paguate 9-14-78	Rio Paguate below confluence @ road ford 9-14-78
Ph	8.1	7.8	8.0	7.9	8.2
TDS (calc.)	679	2,554*	2,113*	2,540*	3,199*
Elec.Cond.,field	600 (9-13-78)	2,620 (9-12-78)	3,100 (9-12-78)	3,050 (9-12-78)	3,100 (9-13-78)
Elec.Cond.,lab	670	2,610	2,270	2,950	2,990
HCO_3^-	215	460	225	225	255
$CO_3^=$	---	---	---	---	---
Cl^-	14	24	28	28	28
$SO_4^=$	305	1,540*	1,330*	1,650*	2,100*
F^-	0.2	0.8	0.6	0.9	0.9
Na^+	130	360	280	330	530
K^+	3	14	11	12	13
Ca^{++}	62	190	205	235	200
Mg^{++}	28	180	130	155	185
SiO_2	31	19	18	18	17
Flow	50 gpm (estimated, 9-13-78)			150 gpm (estimated, 9-12-78)	

Table 7. Minor Dissolved Constituents, Rio Paguate and Rio Moquino, Jackpile-Paguate Mine, New Mexico.

	NMEID Standards	Rio Paguate west weir 11-1-77	Rio Moquino north weir 11-1-77	Rio Paguate south weir 11-1-77	Calculated dispersed inflow through mine area 11-1-77
As	0.1	< 0.01	< 0.01	< 0.01	
Ba	1.0	0.6	0.7	0.6	0.2
Cd	0.01	< 0.01	< 0.01	< 0.01	
Cr	0.05	< 0.01	< 0.01	< 0.01	
CN	0.2	< 0.01	< 0.01	< 0.01	
Pb	0.05	0.03	0.03	0.04	0.09*
Hg	0.002	< 0.001	< 0.001	< 0.001	
Se	0.05	< 0.01	< 0.01	< 0.01	
Ag	0.05	0.02	0.02	0.02	0.02
Cu	1.0	< 0.1	< 0.1	< 0.1	
Fe	1.0	0.12	< 0.05	< 0.05	
Mn	0.2	0.22*	< 0.05	0.21*	0.78*
Phenols	0.005	< 0.001	< 0.001	< 0.001	
Zn	10.0	< 0.1	< 0.1	< 0.1	
Al	5.0	0.8	0.4	2.4	11.6*
B	0.75	< 0.1	< 0.1	< 0.1	
Co	0.05	< 0.01	< 0.01	< 0.01	
Mo	1.0	< 0.1	< 0.1	< 0.1	
Ni	0.2	< 0.01	< 0.01	< 0.01	
V	---	< 0.1	< 0.1	< 0.1	
PO_4	---	< 0.1	< 0.1	< 0.1	

Note: All values in mg/l.
*Concentration exceeds standard.
Analysis by The Industrial Laboratories Company, Denver, Colorado.

Table 8. Dissolved Radiological Constituents, Rio Paguate and Rio Moquino, Jackpile-Paguate Mine, New Mexico.

	Date	Uranium, mg/l	Radium-226, pCi/l
NMEID Standard		5.	30. (in combination with Ra-228)
Rio Paguate, west weir	11-1-77	< 0.006	0.08±0.04
Rio Moquino, north weir	11-1-77	< 0.006	0.10±0.04
Rio Paguate, south weir	11-1-77	0.08±0.006	1.51±0.09
Calculated dispersed inflow through mine area	11-1-77	0.47	8.32
Rio Paguate @ culvert in western mine area	9-14-78	0.020*	0.57±0.06
Rio Paguate above confluence with Rio Moquino	9-14-78	0.58*	4.8±0.2
Rio Moquino @ falls on north	9-14-78	0.034*	0.10±0.05
Rio Moquino above confluence with Rio Paguate	9-14-78	0.15*	2.1±0.1
Rio Paguate below confluence @ road ford	9-14-78	0.39*	3.9±0.2

Note: Analyses are on filtered samples. Results represent concentrations in solution.

Uncertainty is one standard deviation due to counting statistics. Detection limits are one standard deviation.

*Analysis agency - CDM/ACCU-LABS, Wheat Ridge, Colorado. All other analyses by LFE Environmental Analysis Laboratories, Richmond, California.

Calculated apparent concentrations of radiological constituents (Table 8) fall within the ranges found for Jackpile ground water (Section 3.3.3), and are much lower than for the pond south of Rabbit Ear pond (Table 2).

Analytical data on minor constituents (Table 7) indicate that concentrations do not increase significantly through the mine area.

4.2 STREAM SURVEY OF SEPTEMBER 1978

A stream survey was undertaken during September 12 through 14, 1978. This included: 1) field observation of flow characteristics of the streams and field determination of electrical conductivity of the stream water and 2) sampling of stream water for laboratory analysis. The purposes were to follow up on the earlier survey and to identify gaining and losing stretches, to obtain information on gain of high TDS water, and to locate possible seeps. The weirs of the preceding survey had been washed out and new weirs were not installed.

Rio Paguate was flowing without interruption across the western portion of the mine. Flow was estimated as about 50 gpm at the road culvert immediately upstream from station 5950 (Figure 7). The water at this point was of relatively low chemical concentration (Table 6, Figure 7). Downstream from this point flow decreased progressively by infiltration, eventually ceased altogether, and did not commence again until station 5900 (Figure 7).

Flow continued to increase toward the confluence where a rough estimate was 20 gpm. The Rio Paguate water at this point was entirely gain from the ground-water body and was a sodium-magnesium-sulfate type of 2,554 mg/l TDS (Table 6). This water is intermediate in ionic composition and TDS concentration between the calcium-sulfate-bicarbonate water of test wells #1, 2, and 10 (TDS, ~1,000 mg/l) and the magnesium-sodium-sulfate type of the pond south of Rabbit Ear pond (TDS, 2,613 mg/l) (Figure 6). This gain water is similar in chemical composition to that of the calculated dispersed inflow of the earlier survey, although of substantially lower TDS concentration (Table 6 - 2,554 mg/l vs. 4,890 mg/l).

Rio Moquino showed a slight gain in TDS concentration from the north boundary of the mine to the confluence with Rio Paguate (Table 6). However, ionic ratios of this sodium-magnesium-calcium-sulfate water did not change over this reach (Figure 6).

Field examination by walking out the streams and covering the area of the confluence in detail disclosed no visible seeps of ground water.

5.0 SUMMARY

P-10 Ponds

The water of the P-10 ponds was a sodium-sulfate-bicarbonate type (Table 9, #6) that was indistinguishable on a chemical basis from the ground water of the adjacent Jackpile aquifer (Table 9, #7). However, the pond water was high in radiological constituents by a factor of ten relative to the Jackpile water. This difference was due either to the specific source of the P-10 water in the mineralized Jackpile sandstone of the P-10 workings or to exposure of the water to uranium mineralized materials during and/or after removal of the water from the workings.

The surface of the P-10 ponds was above the potentiometric surface of the Jackpile ground-water body. Although a layer of fine-grained material covered the bottom of the ponds and the underlying Jackpile sandstone is relatively impervious, downward seepage discharge of pond water could have occurred. However, no evidence exists that such leakage occurred in large volume. First of all, the ability of the ponds to maintain a water level 15 feet or more above the potentiometric surface of the aquifer (Figure 3) indicates that hydraulic connection, if any, was not conducive to the seepage of large quantities of pond water. Second, because of the similarity in chemical composition of the potential discharge water and the receiving water, discharge

Table 9. Summary of Chemical and Radiological Characteristics of Eight Waters, Jackpile-Paguate Mine, New Mexico.

	Water	Type	TDS, mg/l	Uranium, mg/l	Ra-226, pCi/l
1.	Pond south of Rabbit Ear pond 12-21-77	Mg-Na-SO_4 (Table 1)	2,613	2.2	39.
2.	Dispersed inflow through mine area 11-1-77	Mg-Na-SO_4 (Table 6)	4,890	0.47	8.32
3.	Gain of Rio Paguate between station 5900 and confluence 9-14-78	Na-Mg-SO_4 (Table 6)	2,554	0.58	4.8
4.	Ground waters of test wells #1, 2, and 10	Ca-SO_4-HCO_3 (Table 1)	1,054 (average)	0.15 (average)	7.4 (average)
5.	Rio Moquino at confluence 9-14-78	Na-Mg-Ca-SO_4 (Table 6)	2,540	0.15	2.1
6.	P-10 ponds composite 12-20-77	Na-SO_4-HCO_3 (Table 1)	1,219	1.2	86.
7.	Ground waters of test wells #3-9 and 11	Na-SO_4-HCO_3 (Table 1)	1,127 (average)	0.13 (average)	8.4 (average)
8.	Rabbit Ear pond 12-21-77	Na-SO_4 (Table 1)	4,888	3.1	26.

could only be identified on the basis of unusually high concentrations of uranium and Ra-226 in down gradient ground water. Concentrations of uranium and Ra-226 in test well #11 which is 2,000 feet down gradient from the ponds are below average for Jackpile ground waters (Table 2) and give no indication of admixed P-10 pond water. Third, no evidence exists for a recharge mound on the potentiometric surface of the Jackpile ground-water body. Such a mound would be expected to occur in the relatively impervious Jackpile if seepage discharge were substantial in volume.

In the event that seepage has occurred but has gone undetected, it is unlikely that movement has been widespread. Average interstitial pore velocity of ground water in the vicinity of the P-10 ponds is low, and can be estimated using Darcy's law:

$$\bar{v} = \frac{KI}{\theta} \qquad (1)$$

where: $\bar{v}$ = average interstitial pore velocity, feet per day;

K = hydraulic conductivity, feet per day;

I = hydraulic gradient, feet per feet; and

θ = fractional cross sectional area of flow.

The Jackpile sandstone contains a relatively high interstitial clay content. A reasonable value for K is one foot per day. This is probably on the high side. The gradient in the vicinity of the P-10 ponds is 0.01 (p.17), and a

reasonable value for θ is 0.10. Solution of equation (1) gives $\bar{v}$ equal to 0.1 feet per day, or about 40 feet per year toward the east and northeast. The low velocity indicates that any seepage that may have occurred would not have moved an appreciable distance in the aquifer. As discussed, a recharge mound which could give somewhat higher gradients and, therefore, somewhat higher velocities does not appear to have existed.

The western P-10 pond disappeared by filling by waste some time ago. As of spring 1979, the eastern P-10 pond is being backfilled and is no longer receiving water.

Rabbit Ear Pond

Much the same line of reasoning applies to the Rabbit Ear pond. This pond maintained a water level ten to fifteen feet above the potentiometric surface of the Jackpile ground-water body. The ability to maintain this head difference, the relatively impervious nature of the Jackpile, and the lack of a recharge mound suggest that seepage discharge from the pond was limited or non-existent. Three test wells (#1, 2, and 8) which are down hydraulic gradient from Rabbit Ear pond show no evidence of admixture of the chemically and radiologically distinctive Rabbit Ear pond water.

In the event that seepage has occurred but has gone undetected, it is unlikely that movement has been widespread. This is because velocities of ground-

water movement in the Jackpile aquifer in the vicinity of Rabbit Ear pond are extremely low due to the relatively low hydraulic conductivity of the unit and the very low hydraulic gradient. Velocity of movement of ground water toward the southeast is estimated to be on the order of several tens of feet per year.

Source of Ground-Water Gain by Streams

The evidence is strong that Rio Paguate and Rio Moquino receive discharge of ground water in the vicinity of the confluence and that fluxes of chemical and radiological species increase through the same reach. Although visible seeps were not found of discharging ground water of high concentrations of chemical and radiological species, in the absence of evidence to the contrary it is reasonable to attribute the increases in chemical fluxes to the discharging ground water.

Evidence previously cited in this section shows that the P-10 ponds and Rabbit Ear pond were not the source of the relatively poor quality ground water which is discharged to the streams. However, the evidence is not clear at this point as to the exact identity of the source, or sources, of this poor quality ground water. We know that the sources are not the ponds in question.

The following discusses several possible sources. The gain in Rio Paguate immediately above the confluence could be largely underflow from the Rio

Moquino moving to the south through the unconsolidated sand and silt immediately northwest of the confluence. The analyses of 9-14-78 for Rio Moquino above the confluence and the gain of Rio Paguate between station 5900 and the confluence (Table 9, #5 and 3) are suggestive of this. These waters are similar in chemical composition (Table 6, Figure 6), but differ in concentrations of radiological constituents (Table 8). However, this mechanism does not account for the known increase in total stream flow through this reach.

An alternative explanation is that a mixture of Rio Moquino water and discharging Jackpile calcium-sulfate-bicarbonate ground water (test wells #1 and 2) is responsible for the gain in Rio Paguate. This would require that the plots on a trilinear diagram of the Rio Paguate gain water (PA, Figure 6) lie on mixing lines between the plots of waters of test wells #1 and 2 and Rio Moquino above the confluence (MA, Figure 6). This is the case for the anion and combined anion and cation fields of Figure 6, but is not the case for the cation field. This discrepancy casts doubt upon the validity of this explanation.

An additional possible explanation is that the Rio Paguate gain of 9-14-78 is some mixture of three components - Rio Moquino water and discharging Jackpile ground water of calcium-sulfate-bicarbonate (test wells #1 and 2) and magnesium-sodium-sulfate (pond south of Rabbit Ear pond) types. This explanation is consistent with the trilinear diagram of Figure 6 where all

four waters (PA, MA, #1-2, and RES) lie on mixing lines in each of the three fields.

The dispersed inflow through the mine area of 11-1-77 (D, Figure 6) is similar in type (magnesium-sodium-sulfate) to the pond south of Rabbit Ear pond (RES, Figure 6) with the exception that D is high in TDS and low in radiological constituents relative to RES (Table 9).

In summary, it is clear that the stream system gains water through the mine area by discharge of ground water. This occurs principally in the vicinity of the confluence of the Rio Moquino and Rio Paguate. The source and chemical and radiological type of this ground-water discharge are not certain except that they are not attributable to the Rabbit Ear pond and the P-10 ponds.

6.0 SOURCES OF INFORMATION

Dames and Moore, 1976, Mining and Reclamation Plan, The Anaconda Company's Jackpile-Paguate Uranium Mine, Valencia County, New Mexico, report to The Anaconda Company.

Environmental Protection Agency, 1975, Impacts of Uranium Mining and Milling on Surface and Potable Waters in the Grants Mineral Belt, New Mexico, National Enforcement Investigations Center, Denver, Colorado, Report EPA/330/9-75/001.

Moench, R.H., 1963a, Geologic Map of the Seboyeta Quadrangle, New Mexico, U.S. Geological Survey, Map GQ-207.

Moench, R.H., 1963b, Geologic Map of the Laguna Quadrangle, New Mexico, U.S. Geological Survey, Map GQ-208.

Moench, R.H. and J.S. Schlee, 1967, Geology and Uranium Deposits of the Laguna District, New Mexico, U.S. Geological Survey, Professional Paper 519.

Schlee, J.S. and R.H. Moench, 1963a, Geologic Map of the Moquino Quadrangle, New Mexico, U.S. Geological Survey, Map GQ-209.

Schlee, J.S. and R.H. Moench, 1963b, Geologic Map of the Mesita Quadrangle, New Mexico, U.S. Geological Survey, Map GQ-210.

This Page Left Intentionally Blank

TRIP REPORT

FOR

JACKPILE PAGUATE URANIUM MINE ESI
SR 279
PAGUATE, CIBOLA COUNTY, NEW MEXICO

Prepared for

U.S. Environmental Protection Agency
Linda Carter, Project Officer
1445 Ross Avenue
Dallas, Texas 75202

Contract No. EP-W-06-042
TDD No. TO-0019-10-11-01
WESTON W.O. No. 20406.012.019.0603.01
NRC No. N/A
FPN N/A
CERCLIS ID NMN000607033
EPA SAM Brenda Nixon Cook
START-3 PTL Michelle Brown

Submitted by

Weston Solutions, Inc.
Robert Beck, VP, P.E., Program Manager
70 NE Loop 410, Suite 600
San Antonio, Texas 78216
(210) 308-4300

3 June 2011

TRIP REPORT

1. PROJECT IDENTIFICATION

Date: 3 June 2011

To: Brenda Nixon Cook, Site Assessment Manager (SAM)
U.S. Environmental Protection Agency (EPA)
Region 6, Prevention and Response Branch

Through: Linda Carter, Project Officer (PO)
EPA Region 6, Program Management Branch

Through: Robert Beck, VP, P.E., Weston Solutions, Inc. (WESTON®)
EPA Region 6, Superfund Technical Assessment and Response Team (START-3)
Program Manager

From: Michelle Brown, WESTON
EPA Region 6, START-3 Project Team Leader

Subject: Trip Report: Jackpile-Paguate Uranium Mine ESI
SR279, Paguate, Cibola County, New Mexico
Contract No. EP-W-06-042
TDD No. TO-0019-10-11-01
W.O. No. 20406.012.019.0603.01
NRC No. N/A
FPN N/A
CERCLIS ID NMN000607033
Latitude 35° 8’ 16.74” North
Longitude 107° 20’ 51.84” West

Latitude and longitude coordinates were measured from the approximate center of the former mine and were determined using a scaled aerial photograph and ESRI geographical information system (GIS) ArcMap Software.

2. SITE LOCATION AND DESRIPTION

The Jackpile-Paguate Uranium Mine Site is located on the Laguna Indian Reservation about 40 miles west of Albuquerque in Paguate, Cibola County, New Mexico. The site is located in an area of canyons and arroyos to the east of the village of Paguate and can be reached by taking SR

124 off of interstate 40, 1.7 miles west, then turning right or north on SR 279 and continuing approximately 6.5 miles.

The property on which the former uranium mine is located encompasses approximately 7,868 acres. Approximately 2,656 acres of this property were disturbed by mining operations and contained three open pits that were between 200 and 300 feet deep; 32 waste dumps; and 23 protore stockpiles.

The remaining surrounding area is mainly undeveloped and consists of a varied topography containing wildlife consisting of elk, antelope, goats, and mule deer, and approximately 1,500 domesticated cattle are grazed on the Laguna Reservation (Reference 6). The perennial rivers Rio Moquino and Rio Paguate bisect the site near its center. The Rio Moquino flows southeasterly into the Rio Paguate within the site, and the Rio Paguate continues to flow south of the site through the Paguate Reservoir and then becomes the Rio San Jose.

The mine was operated by Anaconda Minerals Company, a division of the Atlantic Richfield Company, from 1953 through 31 March 1982. The mine was closed because of a sustained fall in the price and demand for uranium.

During its operation, open pit mining was conducted with large front-end loaders and haul trucks. The overburden, consisting of topsoil, alluvium, shale, and sandstone, was blasted or ripped, removed from the open pits, and placed in waste dumps. Underground mining was conducted by driving adits, or declines, to the ore zone. The ore was removed by modified room and pillar methods. Mine water was collected in sumps and pumped to ponds in the open pits. Waste rock was placed in waste dumps. The ore was segregated and shipped by rail to the Anaconda mill, 40 miles west of the mine. Ore was also trucked out in open top trainers which were supposed to be covered but most of the times were not. Therefore, ore was scattered along old highway 279 from the numerous accidents on the hill called Questa.

During the 29 years of mining, approximately 400 million tons of earth was moved within the mine area, and about 25 million tons of ore was removed.

3. SUMMARY OF ACTIONS

On 29 November 2010, the U.S. Environmental Protection Agency Region 6, Prevention and Response Branch (EPA-PRB) tasked the Superfund Technical Assessment and Response Team (START-3) contractor, to perform Expanded Site Inspection (ESI) sampling of the Jackpile-Paguate Uranium Mine (Jackpile) site. As part of this tasking, a Quality Assurance Sampling Plan (QASP) and a Health and Safety Plan (HASP) were prepared and approved by the EPA Site Assessment Manager (SAM) prior to site mobilization.

On 19 thorough 21 April 2011, START-3 collected 9 surface water samples (including 1 duplicate), and 10 sediment samples (including 1 duplicate) from Rios Moquino and Paguate and 14 ground water samples (including 2 duplicates) from existing permanent monitoring wells on and around the Jackpile site. Background samples were collected to establish whether a release of contaminants from the site could be established. To do this samples were collected upstream of the mine. Refer to Attachment B for sample locations. The samples were collected according to the QASP approved by the EPA SAM. Samples were collected using two teams made up of two START-3 contractors each. One team focused on groundwater sample collection and one team focused on surface water and sediment sample collection. The ground water samples were collected using low-flow sampling techniques using a Grundfos Redi-flo pump for all wells except MW-8 and MW-RM which were bailed. Readings for temperature, pH, conductivity, dissolved oxygen and oxygen reduction potential were collected for both groundwater and surface water samples in the field using an YSI 600XL water quality meter. Field parameters were entered onto field log sheets (see Attachment F) and sampling activities were logged by START-3 in field logbooks (Attachment G). Field conditions were also documented through photographs included in Attachment E. Groundwater samples were collected once water quality parameters stabilized. Surface water samples were collected into pre-cleaned 1 gallon jugs by submerging the sample container into the water and facing the mouth of the container upstream while sampling personnel stood downstream. All water samples were field filtered through a 0.45 µm membrane filter and placed in appropriate sample containers. Sediment samples were collected 0 to 2 inches below ground surface, using disposable plastic scoops and placed directly into the appropriate containers provided by the laboratory.

The samples were hand delivered to Summit Laboratory, located in Albuquerque, New Mexico on 22 June 2011. All samples were analyzed for: Isotopic Uranium (isotopes 234, 235, and 238) by method Eichrom ACW-03-15 and ACW-10; total metals by EPA method 200.7 for water and 6010B for solids; selenium by EPA method 6020; mercury by EPA method 7470A/7471A; Gross Alpha by method SM7110C; Gross Beta by EPA method 900; Radium-226 by EPA method 903; and Radium-228 by EPA method 904. In addition, all water samples were also analyzed for: Alkalinity by method SM2310-B; Bicarbonate by method SM-17 2320; Carbonate by method SM 4500-CO2D; Total Dissolved Solids by method SM 2540-C; and Anions by EPA method 300.

Final analytical results were received from the laboratory between 16 May 2011 and 6 June 2011. Radiological data was validated by a professional health physicist. Inorganic data was validated using EPA-approved data validation procedures in accordance with the EPA *CLP National Functional Guidelines* for Inorganic Data Review (October 2004). A summary of the data validation findings were presented in Data Validation Summary Reports included as Attachment H. A summary table of analytical results is presented in Attachment C. A complete table of analytical data is presented in Attachment D. Final analytical reports from the laboratory are included in Attachments H and I.

4. LIST OF ATTACHMENTS

A. Facility Layout Map

B. Sample Location Map

C. Summary of Analytical Results

D. Complete Analytical Results

E. Photographic Documentation

F. Field Data Sheets

G. START-3 Site Logbooks

H. Summit Environmental Technologies Final Analytical Report for Jackpile ESI

I. American Radiation Services Final Analytical Reports for Jackpile ESI (excerpts)

J. Analytical Data Validation Reports for Jackpile ESI

K. TDD No. TO-0019-10-02-01 and Amendment A

Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	B.G. (@ road)	At location	At H_2O	At sed.
RP-JM-01	35.13280°N	-107.34650°E	5998 ft	11 uR	16 uR	12 uR.	14 uR

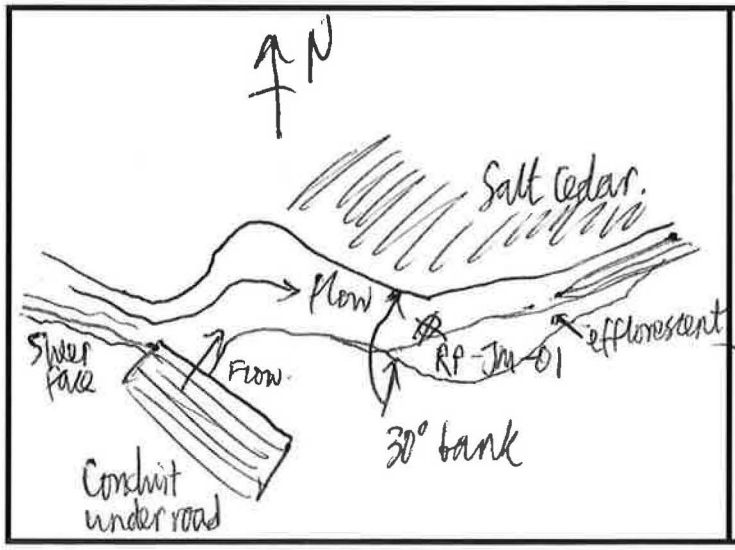
Date	Time	Stream Width	Stream Depth	Description of flow
20-April-2011	1540	4ft.	~10"	steady

1540 SW.

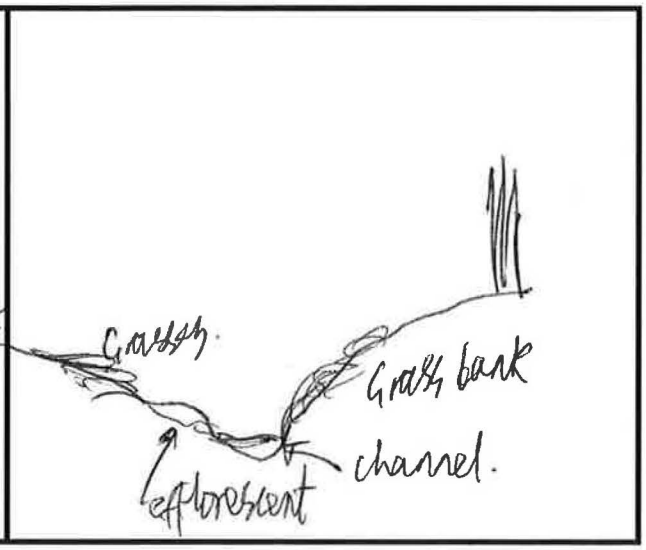
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time	At bed	At Surface		
1				0.16 m/s	0.15 m/s		
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1555	8.11	20.49	2154 us/cm	—	89%	129.7	—

sed @ 1555

7.96 mg/L
6.6 k-1 mm Hg

Surface Sediment Description

Sediment Type (clastic/efflorescent):			both.		
Color	Yellow/brown	Grain Size:	sandy loam	Moisture:	moist

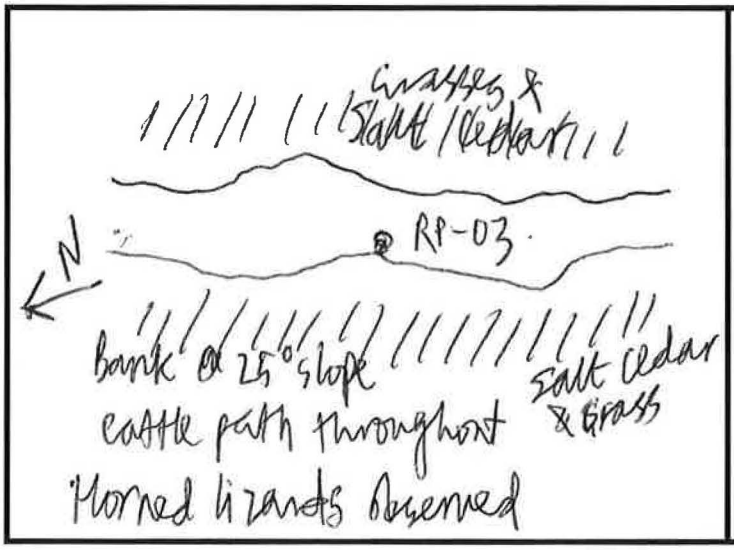
Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	BG @ car	At loc.	At SED	
RP-03	35.07877°N	107.3277E	5739 ft	8 uR	22 uR	18 uR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
20-April-2011	1010	8-9 ft.	18"	DRY (very dry)			

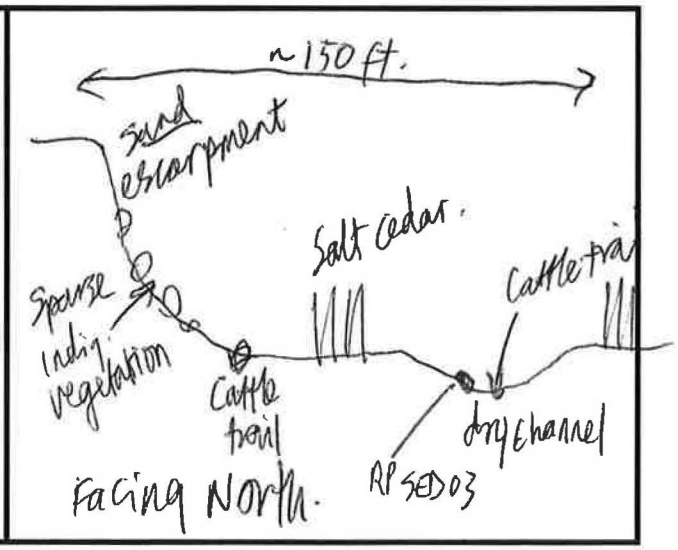
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time				
1	NO WATER - NO FLOW - very dry.						
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color	Gray/Brown	Grain Size:	Silt/clay	Moisture:	None

Field Data Entry Sheet: Surface Water

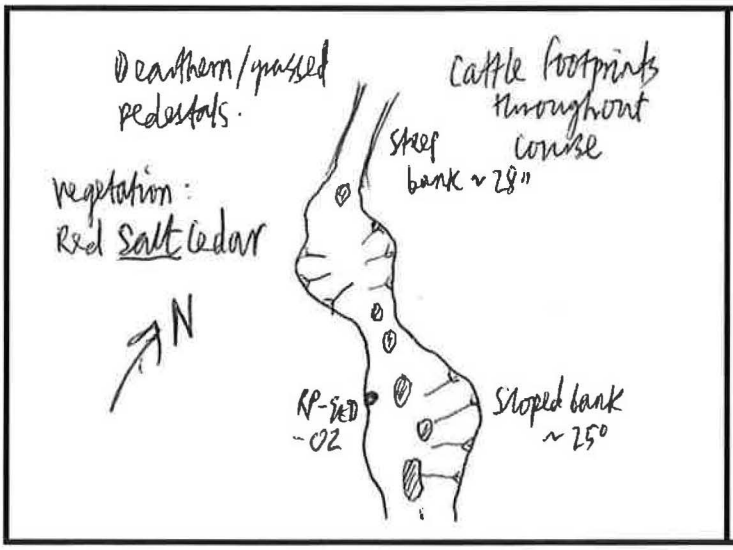
Loc ID	Lat	Lon	Ground Elevation	Rad@LOC	Rad@SED		
RP-02	35.10704°N	-107.32478°E	5785 ft	15 uR	13 uR		
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
April 20 2011	0920	8-10 ft.	3-4' from bed to bank surface.	NO WATER			

Collect sed @ 0925.

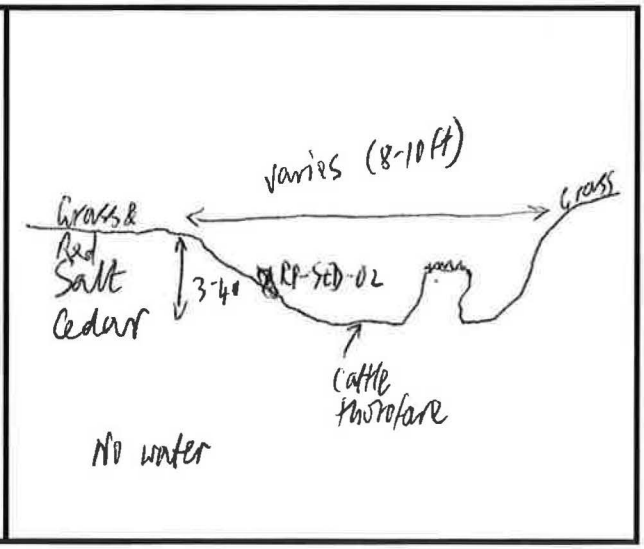
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time				
1	NO WATER						
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color	light brn	Grain Size:	silt/clay	Moisture:	medium.

Field Data Entry Sheet: Surface Water

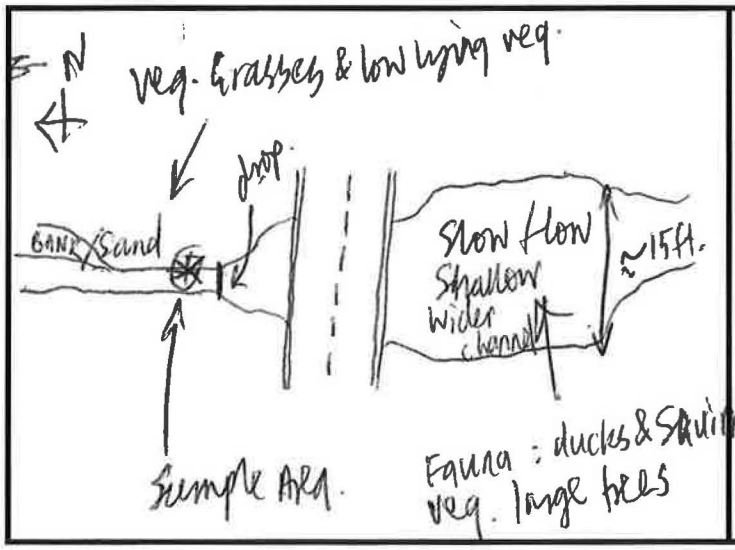
Loc ID	Lat	Lon	Ground Elevation	Rad@loc	Rad@ H_2O	Rad@ Sed.	
RP-BG	35.14095 N	-107.38322 E	8264 ft.	~12 μR	~5 μR	.7 μR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
19-APRIL-11	1025	~30 IN.	~6 in				
				Fast flow at sample location (see sketch)			

Surface Water Flow Data

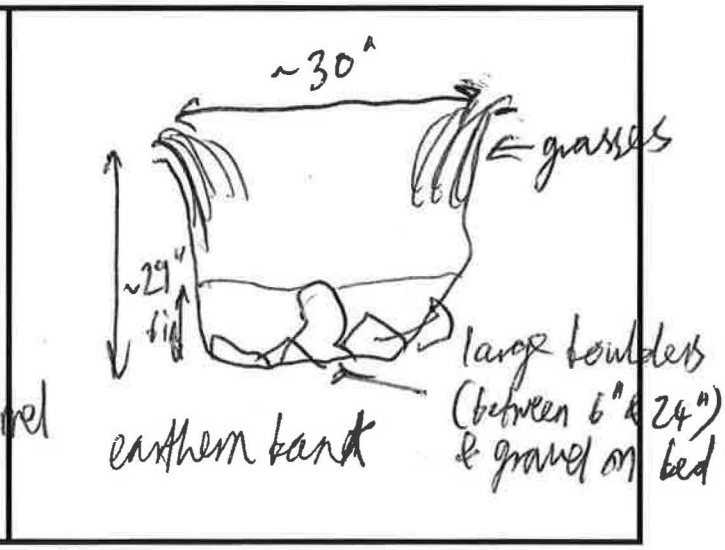
Flow meter, FLO-MATE 2000 ID# 10816

Measurement	Stream Test Length	Begin Time	End Time				
1	N/A	N/A	N/A	At bed	0.03 m/s		
2				At surface	0.25 m/s		
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

VSI 650

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1100	9.61	12.06°C	818 uS/cm	N/A	71.7%	115.1	N/A

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color	Brown	Grain Size:	Fine	Moisture:	Wet

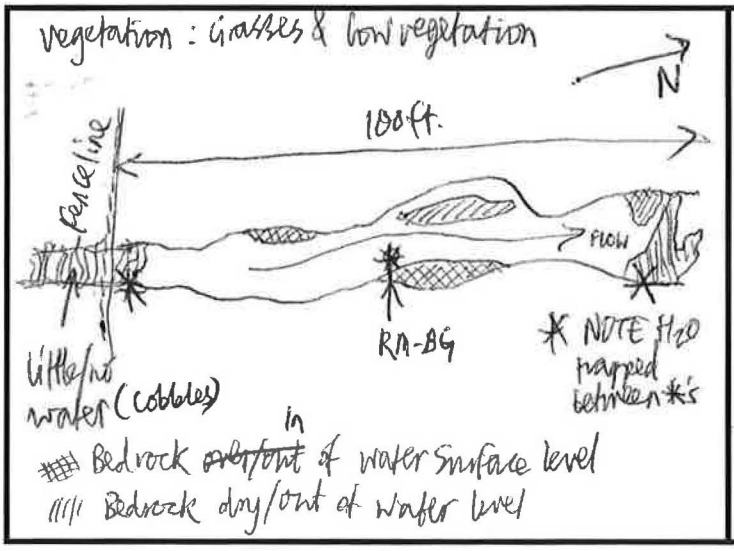
Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	RAD@ LOC	RAD@ H_2O	RAD@ SED	
RM-BG	35.15328°N	-107.35580E	5970ft	~10μR	~11μR	9μR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
19-APR-2011	1425	8-10ft	~12"	NONE, ↑winds.			

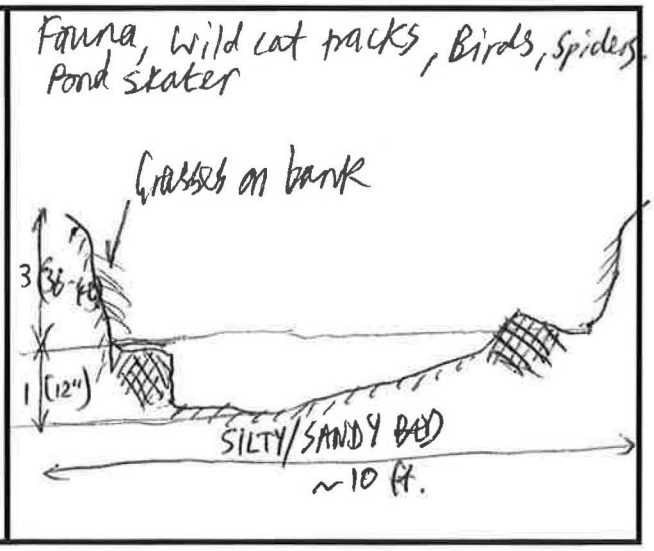
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time	bed	Surface		
1				0.01 m/s	0.02 m/s		
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1435	9.34	20.60°C	1686 μs/cm²	—	7.8%	-149.8	—

Surface Sediment Description

Sediment Type (clastic/efflorescent):							
Color	Brown w/ organic material	Grain Size:	Silt/some sand	Moisture:	High.		

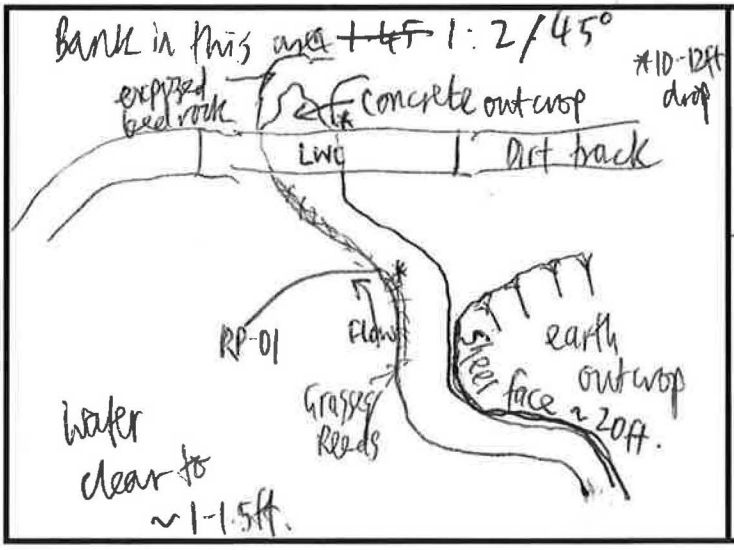
Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	Rad@loc	Rad@H_2O	Rad@Sed	
RP_01	35.1233°N	-107.33646°E	5843 ft	15 μR	13-14 μR	14 μR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
19-April-2011	1540	~15 ft	upto 1 ft.	Mild.			

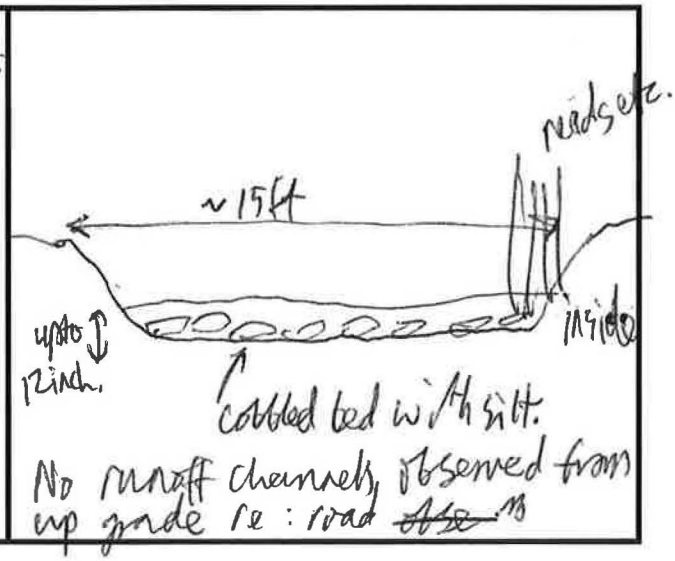
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time	bed	Surface		
1				0.02 m/s	0.03 m/s		
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1555	9.99	20.52°C	2733	—	111.6% 613.5 mmHg	115.7	—

Surface Sediment Description

Sediment Type (clastic/efflorescent):			efflorescent present		
Color	White/brn	Grain Size:	silty sand	Moisture:	moist.

Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	Background	At location	At SW	At SED
PR	35.07299N	-107.33237E	~5745740	8 uR	22 uR	16 uR	12 uR

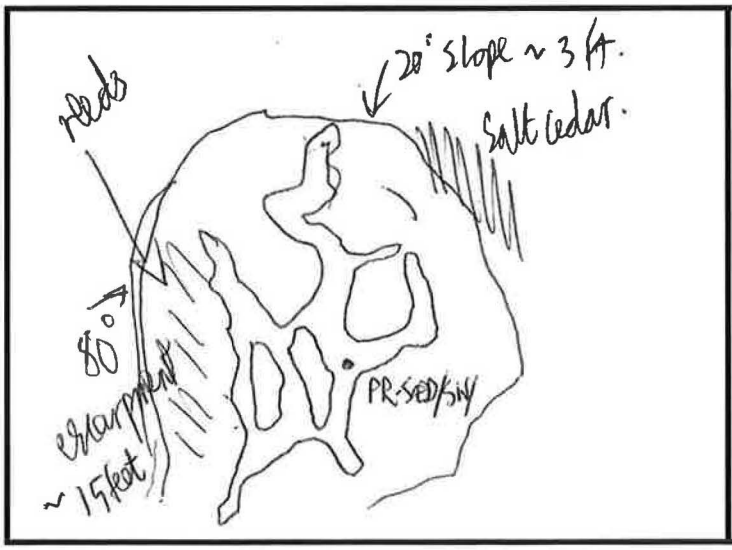
Date	Time	Stream Width	Stream Depth	Description of flow
20-APR-11	~~1045~~		18" in	NONE

~~1130~~ 1135 SW ~~1145~~ 1150 SED. Places.

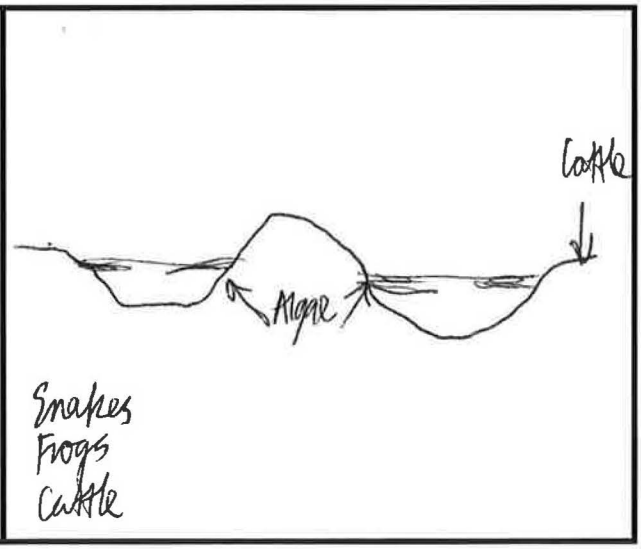
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time				
1	NONE						
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1140	7.84	18.79°C	6179	—	120.9%	90.7	—

11.13 mg/L 6.19.8 mg/kg.

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color		Grain Size:		Moisture:	

Field Data Entry Sheet: Surface Water

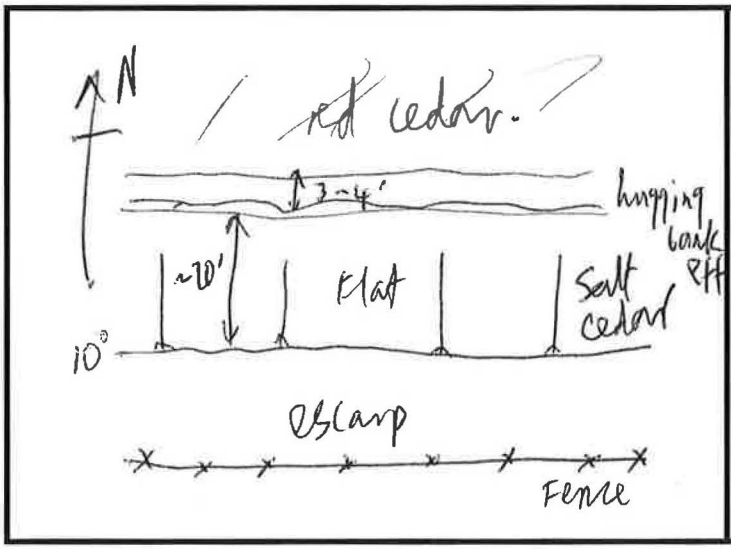
Loc ID	Lat	Lon	Ground Elevation	Rad 8.4	Rad H2O	Rad SED	
RM-JM	35.13310	-107.31701	~5891	11 μR	14 μR	12 μR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
20-APR-2011	1705	3.5 ft.	2"	steady flow.			

SW-1705 Dup. 1710

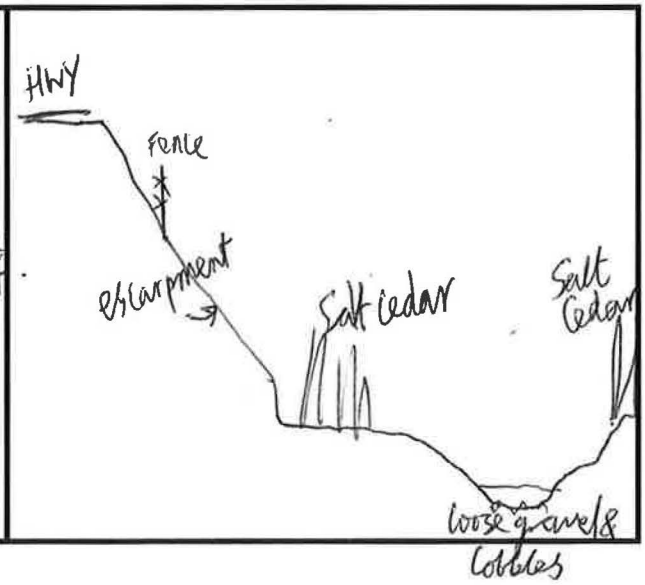
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time				
1				0.06 m/s			
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1705	8.17	20.55°C	2948	—	106.9%	131	—

9.53 mg/L

Surface Sediment Description

Sediment Type (clastic/efflorescent):			both.		
Color	Sandy loam	Grain Size:	yellow/brn	Moisture:	medium

Field Data Entry Sheet: Surface Water

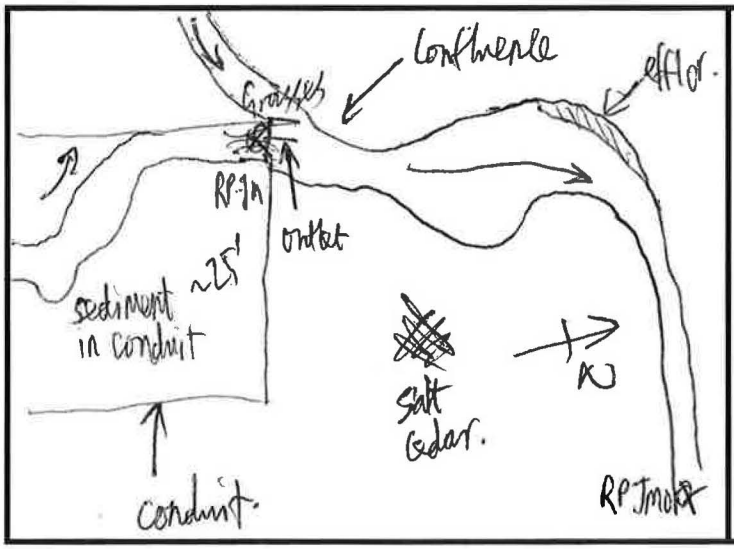
Loc ID	Lat	Lon	Ground Elevation	B.G.	At loc	At H_2O	At Sed
RP-JM	35.13282°N	-107.34673°E	~5891 ft.	11 uR	14 uR	11 uR	12 uR

Date	Time	Stream Width	Stream Depth	Description of flow
20-April-11	1615 SW	@ 1615, 20-04-2011 MAX 6ft.	2 in.	steady flow - slow.

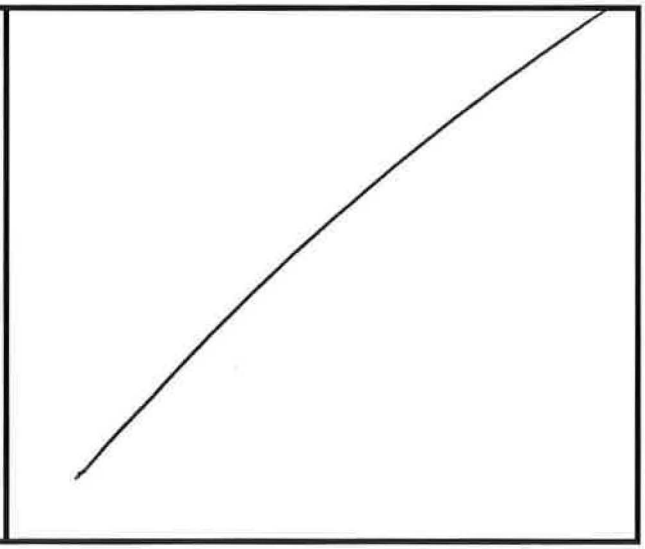
Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time	One reading			
1				0.23 m/s			
2							
3							
4							

Sketch of Test Area



Stream Cross Section



Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1628 Sed @ 1630	8.09	17.89°C	1336	—	82.5% 7.81 mg/L	128.6	—

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color	brn.	Grain Size:	Sandy	Moisture:	high

Field Data Entry Sheet: Surface Water

Loc ID	Lat	Lon	Ground Elevation	Radiation	Radiation loc	H2O	
Makeshift diversion	35.02367°N	-107.32603°E	5734	8 uR	11 uR	7 uR	
Date	**Time**	**Stream Width**	**Stream Depth**	**Description of flow**			
20-April-2011	1400			NONE			

Surface Water Flow Data

Measurement	Stream Test Length	Begin Time	End Time				
1	NO	FLOW					
2							
3							
4							

Sketch of Test Area

Stream Cross Section

Surface Water Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1415	8	21.29	4562 uS/cm	~~0.05~~ /	114.6 %	133.3	/

10.05 mg
619.9 mV

Surface Sediment Description

Sediment Type (clastic/efflorescent):					
Color		Grain Size:		Moisture:	

(GREEN)

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW ~~MD~~ RM	TBD	TBD	TBD	MOUNT	0.00	4	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	~~26.83~~ 29.7	~~13.49~~ 26.95	2.82 ~~13.34~~	0.1666667	0.65	1.8 ~~8.7~~	5.5 ~~26.1~~
Apr-11	29.7	26.90	2.87			1.87	5.6

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity mS/cm	Turbidity	ORP mV	DO % / mg/L
1649	N/A (bailer)	>10 gal	7.79	15.21	1949		101.6	94.2 / 9.27
1652	N/A (bailer)	1.5 gal	7.79	14.42	1918		115.6	97.7 / 9.85
1655	bailer	2.0 gal	7.78	14.10	1905		102.8	96.7 / 9.85
1657	bailer	2.5 gal	7.74	13.89	1913		121.1	98.2 / 10.03
1704	bailer	5 gal	7.81	14.02	1916		97.1	102.1 / 10.46

4/19

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
0934	7.60	14.81	1896		108.2%	111.0	

10.84 mg/L

4/20

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-1	1506789.32	639457.48	6086.93	6087.93	1.00	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	243.3	141.55	101.75	0.2083333	1.02	103.8	**311.4**
Apr-11		142.63	100.67			102.7	308.0

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity µs/cm	Turbidity	ORP mV	DO % / mg/L
1541	10 g/min	0-2	7.66	18.49	2581	—	90.9	26.1 / 2.39
1546	10 g/min	50	7.85	16.82	2478	—	93.5	32.2 / 3.00
1551	10 g/min	100	7.86	16.76	2454	—	105.2	40.2 / 3.48
1556	10 g/min	150	7.86	16.65	2423	—	104.4	31.5 / 2.74
1601	10 g/min	200	7.79	16.77	2420	—	112.9	17.7 / 1.68
1606	10 g/min	250	7.85	16.60	2454	—	120.0	26.5 / 2.46
1611	10 g/min	300	7.78	16.76	2597	—	133.6	37.6 / 3.72

Field Screening Data (Final Sample)

Time	~~Flow Rate~~ ~~pH~~	~~gal~~ ~~Temp~~	~~pH~~ ~~Cond~~	~~Temp~~ ~~Turbidity~~	~~Cond.~~ ~~DO~~	~~turb~~ ~~ORP~~	Alkalinity	DO % / mg/L
1611	10 g/min	300	7.78	16.76	2597	—	133.6.	37.6 / 3.72

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-8							

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	456	N/A	#VALUE!	0	0.00	#VALUE!	#VALUE!
Apr-11	NA	279.45	176.5			227.6	682.7

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity ms/cm	Turbidity	ORP mV
initial 1354	NA	1 Liter	8.05	18.92	1629	—	~~88.8~~
1417	NA	1g	8.02	18.72	1658	—	98.8
1430	NA	2g	7.97	17.83	1656	—	98.2
1452	NA	3g	8.00	17.94	1656	—	103.0

60.0% / 100mV
60.8 / 5.43
58.1 / 5.25
57.0 / 5.33
60.1 / 5.64

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	% DO mg/L	ORP	Alkalinity
1452	8.00	17.94	1656	—	60.1 / 5.64	103.0	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-7	1511270.52	647254.10	6121.09	6122.19	1.10	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	388	164.88	223.12	0.2083333	1.02	227.6	**682.7**
Apr-11		165.82	222.18			227.4	682.3

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity µS/cm	Turbidity	ORP mV	DO mg/L
Initial 1145	10 gal/min	200	~~21.86~~ 8.40 PB	21.93	878		40.7	21.4/1.71
1155	10 g/min	300	8.50	18.87	858		66.9	21.6/2.47
1205	10 g/min	400	8.53	18.28	850		77.7	28.4/2.53
1215	10 g/min	500	8.56	18.10	850		57.9	26.5/2.35
1225	10 g/min	600	8.55	18.08	847		66.1	34.9/3.08
1235	10 g/min		8.65	17.73	819		71.0	31.8/2.94

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	% DO mg/L	ORP	Alkalinity
1235	8.65	17.73	819	—	31.8 / 2.94	71.0	—

(YELLOW)

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW ~~BM~~ MD	TBD	TBD	~6002.00	MOUNT	0.00	4	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	~~29.77~~ 26.8	~~26.95~~ 13.4	133 ~~2.82~~	0.1666667	0.65	8.7 ~~1.8~~	26.1 ~~5.5~~
Apr-11	26.83 ~~29.7~~	13.15 ~~26.90~~	13.68 ~~2.87~~	0.1666667 ~~0.1666667~~		~~2.28~~ 1.87	11.4 ~~5.6~~

* Well volume V=3.1416*(d/24)^2*H*7.4805

8.892 26.676

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C/°F	Conductivity µs/cm	Turbidity	ORP mV	DO % / mg/L
Initial 1753	~~2~~ 100 ml/min	2	8.05	23.35	3319	—	51.2	91.8 / 7.72
1755	~~100~~ 2 l/min	~~22~~ 6	7.46	16.40	6995	—	-128.6	47.9 / 4.57
1800	5 l/min	31	7.40	15.43	7005	—	-124.8	21.1 / 1.96
1802								

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1030	7.74	20.00	6960	—	136.8 % / 12.15 mg/L	115.8	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-2	1500706.22	648932.66	5847.52	5848.42	1.00	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	41.6	21.71	19.89	0.2083333	1.02	20.3	**60.9**
Apr-11		21.37	20.23			20.6	61.9

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity ms/cm	Turbidity	ORP mV	DO % / mg/L
1226	5 g/min	5 g	8.62	20.75	41		14.3	122.6 / 10.78
1229	5 g/min	20 g	7.36	16.61	3617		-38.2	83.8 / 7.77
1230	5 g/min	25 g	7.38	16.20	3689		-90.5	75.5 / 6.92
1232	5 g/min	35 g	7.43	15.82	3831		-122.7	56.3 / 5.24
1236	5 g/min	55 g	7.44	15.80	3909		-140.3	12.1 / 1.12

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	% DO mg/L	ORP	Alkalinity
1023	7.42	18.47	1194	—	137.0 / 12.80	100.8	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-3	1504131.00	643051.93	5950.07	5952.07	2.00	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	62.9	42.43	20.47	0.2083333	1.02	20.9	**62.6**
Apr-11		41.79	21.71			22.1	66.4

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity mS/cm	Turbidity	ORP mV	DO mg/L
1400	5 g/min	0 gal (initial)	8.86	21.61	50	—	28.0	12.1/NR6
1402	5 g/min	10 g	7.27	14.30	1215	—	75.5	108.7/10.59
1404	~~5 g/min~~ 5	20 g	7.14	12.79	1307	—	68.3	98.3/10.17
1406	5 g/min	30 g	7.01	12.56	1305	—	56.3	99.0/9.85
1409	5 g/min	40 g	7.14	12.39	1305	—	58.4	95.5/9.99
1413	5 g/min	60	6.99	12.29	1302	—	94.0	99.7/10.62
1415	5 g/min	70	6.95	11.96	1299	—	101.7	95.0/10.03

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1415	6.95	11.96	1299	—	95.0% / 10.03 mg/L	101.7	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-4	1503734.32	639391.62	6007.26	6008.36	1.10	4	Steel pipe

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	39.85	34.14	5.71	0.1666667	0.65	3.7	**11.2**
Apr-11		33.62	6.23			4.1	12.2

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity µS/cm°	Turbidity	ORP mv	DO % / mg/L
1312	Bailer	0 Liters	7.05	14.47	1776	—	44.4	56.4/5.61
1320	2.5 gal/min	3.5	7.13	15.29	1803	—	55.4	58.8/7.88
1325	2.5 gl/min	7 (dry)	7.07	14.98	1756	—	43.4	65.4/6.30
1328	Bailer	9	7.06	13.73	1787	—	68.7	72.2/7.25
1330	Bailer	10	7.09	13.55	1788	—	68.2	77.0/7.72
1331	bailer	11	~~7.14~~ FB 7.14	13.32	1786	—	66.9	76.5/7.77
~~1335~~ 1333	bailer	12	7.10	13.37	1782	—	62.7	78.2/8.12

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1333	7.10	13.37	1782	—	78.2% / 8.12 mg/L	62.7	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
MW-6	1495801.51	650526.62	5819.18	5820.78	1.60	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	40.45	33.35	7.1	0.2083333	1.02	7.2	**21.7**
Apr-11		34.91	5.54			5.6	16.9

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity µs/cm	Turbidity	ORP mV	DO % / mg/L
1146	5 g/min	(initial)	8.41	21.66	23	—	55.9	119.8 / 10.57
1148	5 g/min	10	7.18	17.20	2442	—	86.2	76.9 / 7.06
1150	5 g/min	20	7.24	15.92	2985	—	-16.2	99.5 / 9.71
1153	1 g/min	23	7.18	15.36	3056	—	-23.5	101.1 / 9.91

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1153	7.18	15.36	3056	—	101.1%	-23.5	—

~~99.1~~ 9.91 mg/L

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
SP-OP-35	1501033.20	634954.17	6060.89	6063.21	2.32	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	83.65	69.71	13.94	0.2083333	1.02	14.2	**42.7**
Apr-11		69.36	14.29			14.6	43.7

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity ms/cm	Turbidity	ORP mv	DO % / mg/L
1450		initial	6.79	18.53	10289	—	112.7	71.3 / 6.30
1453	5 g/min	10 gal	7.12	17.98	10155	—	112.5	103.4 / 9.40
1454 (dry)								
1500	2 g/min	20 gal	6.66	18.64	10514	—	104.3	53.4 / 4.64
1520	Bailer	31 gal	6.83	18.90	10495	—	118.5	78.8 / 7.19
1530 (DRY)								

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	% DO mg/L	ORP	Alkalinity
1112	6.91	19.60	9640	—	82.1 / 7.73	112.5	—

Field Data Entry Sheet: Groundwater

Well ID	N	E	Ground Elevation	Casing Elevation	Stand	Well Diameter (d)	Casing Type
NP-OP-20 E	1505123.28	641582.11	5961.85	5963.93	2.08	5	PVC

Date	Total Depth	Depth to Groundwater	water column height	well radius (feet)	Well Volume per foot (gallons)	water column volume	3x well volume (gallons)
			(H)	r=d/24	=pi*r^2*7.4805	*	= 3 x V
Jun-10	65.55	29.19	36.36	0.2083333	1.02	37.1	**111.3**
Apr-11		29.66	35.9			36.6	109.8

* Well volume V=3.1416*(d/24)^2*H*7.4805

Groundwater Purge Data

Time	Flow Rate	Gallons (total)	pH	Temperature °C	Conductivity µS/cm	Turbidity	ORP mV	DO % / mg/L
1546	8 g/min	initial	6.24	16.09	5269	—	93.4	51.3 / 4.84
1549	8 g/min	24 gal	6.16	14.72	5241	—	115.1	66.9 / 5.58
1551	8 g/min	40 gal	6.23	14.66	5216	—	42.6	70.7 / 6.32
1553	8 g/min	60 gal	6.24	14.58	5257	—	58.5	71.6 / 6.99
1557	8 g/min	92 gal	6.23	14.85	5284	—	49.6	63.4 / 6.19
1559	8 g/min	110 gal	6.29	14.83	5289	—	45.4	77.5 / 7.7

Field Screening Data (Final Sample)

Time	pH	Temp	Cond	Turbidity	DO	ORP	Alkalinity
1559	6.29	14.83	5289	—	77.5% / 7.70 mg/L	45.4	—

JPOP415

NL = 38.71'
TD = 48.43'
Water Column = 9.72
Well Volume X3 = 18.9

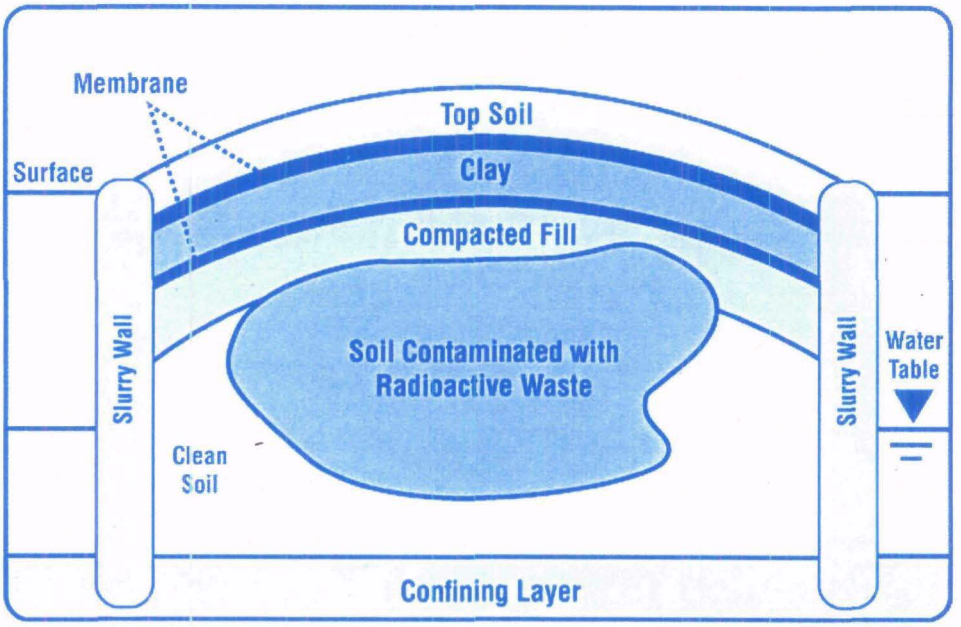
	Time	Flow Rate	Total Gallons	pH	Temp (°C)	Conductivity (µs/cm²)	ORP (mv)	DO%	DO mg/L
4/20	1639	~10g/min		6.76	17.27	5367	60.6	72.0	6.58
	1640 (dry)		~10g						
4/21	0918			7.43	18.01	5067	117.3	129.4	12.05

United States
Environmental
Protection Agency

Office of Radiation and Indoor Air
Radiation Protection Program
(6608J)

EPA 402-R-07-004
October 2007

Technology Reference Guide for Radioactively Contaminated Media



DISCLAIMER

This Technology Guide, developed by USEPA, is meant to be a summary of information available for technologies demonstrated to be effective for treatment of radioactively contaminated media. Inclusion of technologies in this Guide should not be viewed as an endorsement of either the technology or the vendor by USEPA. Similarly, exclusion of any technology should not be viewed as not being endorsed by USEPA; it merely means that the information related to that technology was not so readily available during the development of this Guide. Also, the technology-specific performance and cost data presented in this document are somewhat subjective as they are from a limited number of demonstration projects and based on professional judgment. In addition, all images used in this document are from public domain or have been used with permission.

ACKNOWEDGEMENTS

This Guide was developed by the Radiation Protection Division (RPD) of EPA's Office of Radiation and Indoor Air (ORIA). Mr. Edward Feltcorn of ORIA's Center for Radiation Site Cleanup, served as the Work Assignment Manager.

Several individuals provided valuable input regarding the content of this Guide throughout its development. EPA/ORIA wishes to thank the following individuals for their assistance and technical review comments on the drafts of this Guide:

Schatzi Fitz-James
Rodger Goodman
Brian Littleton

Special thanks goes to the following ORIA staff that were instrumental in the technical review and production of this 2007 updated Guide:

Ronald Wilhelm
Lindsey Bender

This document was prepared by Terranear PMC, Inc., under contract number 4W-2323-YTSX.

FORWARD

The Technology Reference Guidance for Radioactively Contaminated Media (Guide) is intended to aid in the selection of treatment technologies for remediation of radioactively contaminated media. The Guide is designed to help site managers, Remedial Program Managers (RPM), On-Scene Coordinators (OSC), their contractors and others to identify and understand technologies that are potentially useful in the remediation of radioactively contaminated media.

This Guide is designed to give easy access to critical information on applied technologies that address radioactive contamination in solid and liquid media. The solid media includes soils, sediments, sludge and solid waste, but does not include buildings and structures. The liquid media includes groundwater, surface water, leachate and waste water.

The Guide is an update of the 1996 document "Technology Screening Guide for Radioactively Contaminated Site," EPA-402-R-96-017. New technologies have been added. The Guide is primarily targeted at Superfund or Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) sites. It is hoped that it will be useful for other sites facing similar problems.

The Guide is a snapshot in time and may be updated again in the future. If you have any comments on the document or suggestions for incorporation in future updates, please contact:

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
Radiation Protection Division
1200 Pennsylvania Avenue, NW (MC 6608J)
Washington, DC 20460-0001
U.S.
Phone: (202) 343-9290

TABLE OF CONTENTS

LIST OF EXHIBITS

LIST OF EXHIBITS (CONTINUED)

LIST OF APPENDICES

LIST OF ACRONYMS

ACOE	U.S. Army Corps of Engineers
AEA	Atomic Energy Act
AECL	Atomic Energy of Canada, Limited
AFO	Amorphous Ferric Oxyhydroxide
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
ARAR	Applicable or Relevant and Appropriate Regulations
ARM	Accelerator-Produced Radioactive Material
BDAT	Best Demonstrated Available Technology
BNL	Brookhaven National Laboratory
BRAC	U.S. DOD Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CLU-IN	EPA Hazardous Waste Clean-Up Information System
DNA	Defense Nuclear Agency
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DWPF	Defense Waste Processing Facility
EDTA	Ethylenediamine-tetraacetic acid
EPA	U.S. Environmental Protection Agency
FRTR	Federal Remediation Technologies Roundtable
FUSRAP	Formerly Utilized Sites Remedial Action Program
GAC	Granular Activated Carbon
GCC	Greater-Than-Class-C Waste
GW	Groundwater
HDPE	High Density Polyethylene
HEPA	High Efficiency Particulate Air
HLW	High Level Radioactive Waste
IAEA	International Atomic Energy Agency
ISV	In-situ Vitrification
ITRC	Interstate Technology Regulatory Council
KEI	Kapline Enterprises Inc.
LANL	Los Alamos National Laboratory
LEHR	Laboratory for Energy-Related Health Research
NARM	Naturally Occurring and Accelerator-Produced Radioactive Materials
NAVFAC	Naval Facilities Engineering Command
NCP	National Oil and Hazardous Substances Contingency Plan
NORM	Naturally Occurring Radioactive Materials
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OSWER	EPA Office of Solid Waste and Emergency Response
OSC	On-Scene Coordinator
PCA	Portland Cement Association
PCB	Polychlorinated Biphenyl

LIST OF ACRONYMS (CONTINUED)

PCT	Product Consistency Test
PRB	Permeable Reactive Barrier
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
RPM	Remedial Program Manager
ROD	Record of Decision
RTDF	Remediation Technologies Development Forum
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SITE	EPA Superfund Innovative Technology Evaluation Program
SW	Surface Water
TCA	Total Constituent Analysis
TCLP	EPA Toxicity Characteristic Leaching Procedure
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
TIE	DOE Technical Information Exchange
UKAEA	United Kingdom Atomic Energy Agency
UMTRA	Uranium Mill Tailings Remedial Action
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
VOC	Volatile Organic Compound
VORCE	Volume Reduction/Chemical Extraction
WRT	Water Remediation Technology
WSRC	Westinghouse Savannah River Company
ZVI	Zero Valent Iron

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency, Office of Air and Radiation, Radiation Protection Division's Radiation Site Cleanup Center, produced this Technology Reference Guide for Radioactively Contaminated Media (Guide) as a reference for technologies that can effectively treat radioactively contaminated sites. The Guide is designed to give easy access to critical information on applied technologies that address radioactive contamination in solid and liquid media. The solid media include soils, sediment, sludge, and solid waste, but do not include buildings and structures. The liquid media include groundwater, surface water, leachate, and waste water. This information is presented in technology profiles that can be used to compare technologies for site-specific application. This Technology Guide is a revision of "Technology Screening Guide for Radioactively Contaminated Sites," EPA 402-R-96-017, published in 1996.

The profiles include 21 applied technologies that are currently in use at contaminated sites. Of these, there are 13 technologies associated with contaminated solid media that are grouped into six categories:

- containment,
- solidification/stabilization,
- chemical separation,
- physical separation,
- vitrification, and
- biological treatment.

There are eight technologies associated with contaminated liquid media that are grouped into four categories:

- chemical separation,
- physical separation,
- biological treatment, and
- natural attenuation.

In addition to the applied technology profiles, there are brief discussions of five emerging technologies that have been bench- or pilot-tested.

This Guide builds on significant efforts by EPA, the Department of Energy, the Department of Defense, and other agencies to facilitate remedy selection. This Guide also updates information on each technology's operating and performance data.

Profiles for each technology include a basic description, contaminants addressed, waste issues, technology operating characteristics, and site characteristics that affect performance. Each profile provides performance data, cost data, commercial availability, and contacts for technical information and vendors (if available). A list of references is provided at the end of each technology description.

Section 1 introduces the Guide, provides background information on general characteristics of radioactive waste at National Priorities List (NPL) sites, and provides summary tables for the information in this Guide. Section 2 provides profiles for technologies applicable to solid media while Section 3 presents profiles for technologies applicable to liquid media. Section 4 presents a brief discussion of five emerging technologies not yet fully demonstrated. Appendix A provides information about radionuclides present at individual NPL sites and the media affected. A quick reference to radiation concepts and glossary of terms is provided in Appendix B. Appendix C provides suggested references for further reading.

APPENDIX B

RADIOACTIVE CONTAMINATION: BASIC CONCEPTS AND TERMS

RADIOACTIVE CONTAMINATION: BASIC CONCEPTS & TERMS

Types of Radioactive Waste

Although there are hundreds of known radioactive isotopes, only a small fraction of these are likely to be seen at contaminated sites. This effect is due to the fact that many isotopes are nearly impossible to create without exotic scientific equipment and many others have extremely short half-lives and therefore do not exist long enough to make it outside the facility where they were created. Among the radioactive isotopes likely to be encountered in disposal and remediation sites are naturally occurring radioactive material such as uranium-238, thorium-232, thorium-230, radium-226, and radon -222; radioactive fission products such as cesium-137 and strontium-90; and products of neutron bombardment such as cobalt-60. The radioactive isotopes in place at one particular site will depend on the source of the material spilled or disposed of there.

Radioactive isotopes originate from both manufactured and natural sources. Nuclear reactors and particle accelerators, for example, can generate radioactive isotopes by forcefully de-stabilizing their nuclei in a process known as fissioning (splitting of the atom). Fissioning can split larger atoms, such as uranium or plutonium, into multiple, smaller, radioactive elements. Reactors also can create radioactive isotopes from stable elements by causing additional neutrons to be absorbed into their nuclei, which can result in an unstable (energy-emitting) configuration. This is called neutron activation. Additionally, particle accelerators, cyclotrons, and similar machines can create radioactive isotopes from stable elements by bombarding their nucleus with a variety of particles. This process is often used to create medical isotopes.

The development and use of radioactive materials inevitably results in the production of radioactive waste. The treatment and disposal of the potentially harmful waste is a matter of much concern and controversy. Again, the management of this waste has led to the development of definitions and authorities to assign responsibility for their handling. Exhibit B-1 is a summary of categories and definitions, and the authority from which it is cited. The technologies presented in this Guide are most likely to be applicable to low-level, Naturally-occurring and Accelerator-produced Radioactive Material (NARM)/Naturally-Occurring Radioactive Material (NORM), and mixed waste.

Exhibit B-1: Statutory and Regulatory Categories of Radioactive Waste

Category of Radioactive Waste	Definition	Citation
High-Level Waste	Irradiated reactor fuel; liquid waste resulting from the operation of the first-cycle solvent extraction system, or equivalent, and the concentrated waste from subsequent extraction cycles, or equivalent, in a facility reprocessing irradiated reactor fuel; and solids into which such liquid waste has been converted.	Nuclear Waste Policy Act [10 CFR 60]
Low-Level Waste	Radioactive waste not classified as high-level waste, transuranic waste, spent fuel, or byproduct materials such as uranium and thorium mill tailings.	Low-Level Radioactive Waste Policy Act [10 CFR 61]
Class A, B, C, and Greater-Than-Class-C Waste	Low-level waste categorized according to its radionuclide concentration and half-life. In general, Class A waste has the lowest concentrations of particular radionuclides. Class B and C wastes contain radionuclides in higher concentrations. GCC waste exceeds the concentration limits established for Class C waste.	10 CFR 61
Transuranic Waste	Waste containing elements with atomic numbers greater than 92 and half-lives greater than 20 years, in concentrations greater than 100 nCi/g of alpha-emitting isotopes.	40 CFR 191
AEA Waste	Waste containing or contaminated with source, byproduct, or special nuclear material.	Atomic Energy Act
Mixed Waste	Hazardous waste as defined by RCRA containing or contaminated with high- or low-level waste or source, byproduct, or special nuclear material.	Federal Facilities Compliance Act of 1992
NORM/TENORM Waste	NORM, such as that found in soil, rock, and groundwater, can be concentrated through human activity. This is referred to as Technologically-Enhanced Naturally-Occurring Radioactive Material (TENORM). Examples of TENORM include mining wastes such those from uranium mining; energy production wastes such as coal ash, geothermal energy waste scales, and petroleum production waste; and water treatment residues. TENORM does not include source, special nuclear, or by-product material.	State authority

Category of Radioactive Waste	Definition	Citation
ARM/NARM Waste	Accelerator-Produced Radioactive Material (ARM) waste contains or is contaminated with radioactive material produced as a result of nuclear transformations in an accelerator. Examples of ARM waste include accelerator targets used in subatomic particle physics research, accelerator maintenance wastes, and wastes from radiopharmaceutical manufacture. NARM is a broader category that includes both ARM and NORM. ARM and NARM do not include source, special nuclear, or byproduct material.	State authority
Source Material	In general terms, "source material" means either the element thorium or the element uranium provided that the uranium has not been enriched in the isotope uranium-235. Source material is generally used to refer to ores or refined ores containing by weight one-twentieth of one percent (0.05 percent) or more of uranium, thorium, or any combination thereof; depleted uranium; and materials produced during the reprocessing of spent nuclear fuel.	Atomic Energy Act
Special Nuclear Material	Special nuclear material is defined as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. Special nuclear material does not include source material.	Atomic Energy Act
Byproduct Material	Byproduct material is defined in both sections 11.e.(1) and 11.e.(2) of the Atomic Energy Act. Section 11.e.(1) byproduct material is defined as radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or using special nuclear material. Section 11.e.(2) byproduct material is defined as the tailings or waste produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content.	Atomic Energy Act

NATURE OF RADIOACTIVITY

Nearly all elements (e.g., oxygen, carbon) in nature can be found in a variety of nuclear compositions. Isotopes, which are different forms of an element, have the same atomic number, but different atomic mass. That is, their nuclei have the same number of protons but different numbers of neutrons. Carbon, for example, contains six protons in its nucleus but can have either six (carbon-12), seven (carbon-13), or eight (carbon-14) neutrons.

Isotopes that are unstable will undergo radioactive decay in order to reach a more stable nuclear configuration. These unstable isotopes are called radioactive isotopes. Radioactive isotopes spontaneously emit energy and particles in the form of alpha (positively charged) or beta (positively or negatively charged) particles, and/or gamma rays (which are similar to X rays in behavior) as part of the radioactive decay process. This emitted or expended energy—radiation—and its spontaneous activity (radioactivity) form its potentially creative or destructive power. Carbon-14, for example, is a radioactive isotope that will decay by emitting a beta particle and form nitrogen-14.

An alpha particle is a positively charged particle, emitted from the nucleus of a decaying radioactive atom (alpha emitters), containing two neutrons and two protons identical to the nucleus of a helium atom. Because alpha particles are "massive" on an atomic scale, they can be easily shielded and are stopped by a sheet of paper. Thus, they cannot penetrate the natural human dead skin layer on external skin. The alpha particles can be dangerous when the alpha emitting atom is inhaled, or if the atom enters the body through a cut, food, or water, and permitted to come in contact with living cells inside the body to ionize the living tissue. The harmful exposure to alpha particles usually occurs mainly through internal pathways and some can occur through external pathways.

A beta particle is essentially either an electron or a positron emitted from the nucleus of a decaying atom. Most beta particles that are produced in the decay of naturally occurring radioisotopes are electrons. Positrons are usually the result of the decay of certain man-made radioisotopes. Beta particles are less massive than alpha particles but are also relatively easy to shield. Some beta particles can penetrate skin. As with alpha emitters, beta emitters cause the most damage when the atom is ingested and allowed to decay inside the body. The harmful exposure to beta particles usually occurs mainly through internal pathways and some can occur through external pathways.

Gamma rays are similar to x rays (although they are produced differently); however, gamma rays are of higher energy and thus have stronger penetrating power. Gamma rays can penetrate and damage critical organs in the body and are the most difficult of the radiation types to shield. The exposure to gamma rays is usually of concern through external pathways but it can also occur through internal pathways.

Included among the naturally occurring radioactive elements are uranium-238, carbon- 14, hydrogen-3 (tritium), thorium-230, radium-226, radon-222, and potassium-40. In addition, radioactive elements can be created as products of the decay of other radioactive isotopes. When the nucleus of uranium-238 decays, for example, it produces thorium-234 (radioactive),

which, in turn, decays to become protactinium-234. This process of decay continues until a stable element is reached. Sequences such as these are called decay chains. The radioactive decay is usually a first order reaction where disintegration of radionuclide is proportional to the activity present. Exhibit B-2 presents the radioactive decay process for the uranium (U) series. Uranium-238 decays to a final stable atom of lead (Pb-206). The half-life and decay energy for each of the newly formed decay products is also shown in Exhibit B-2.

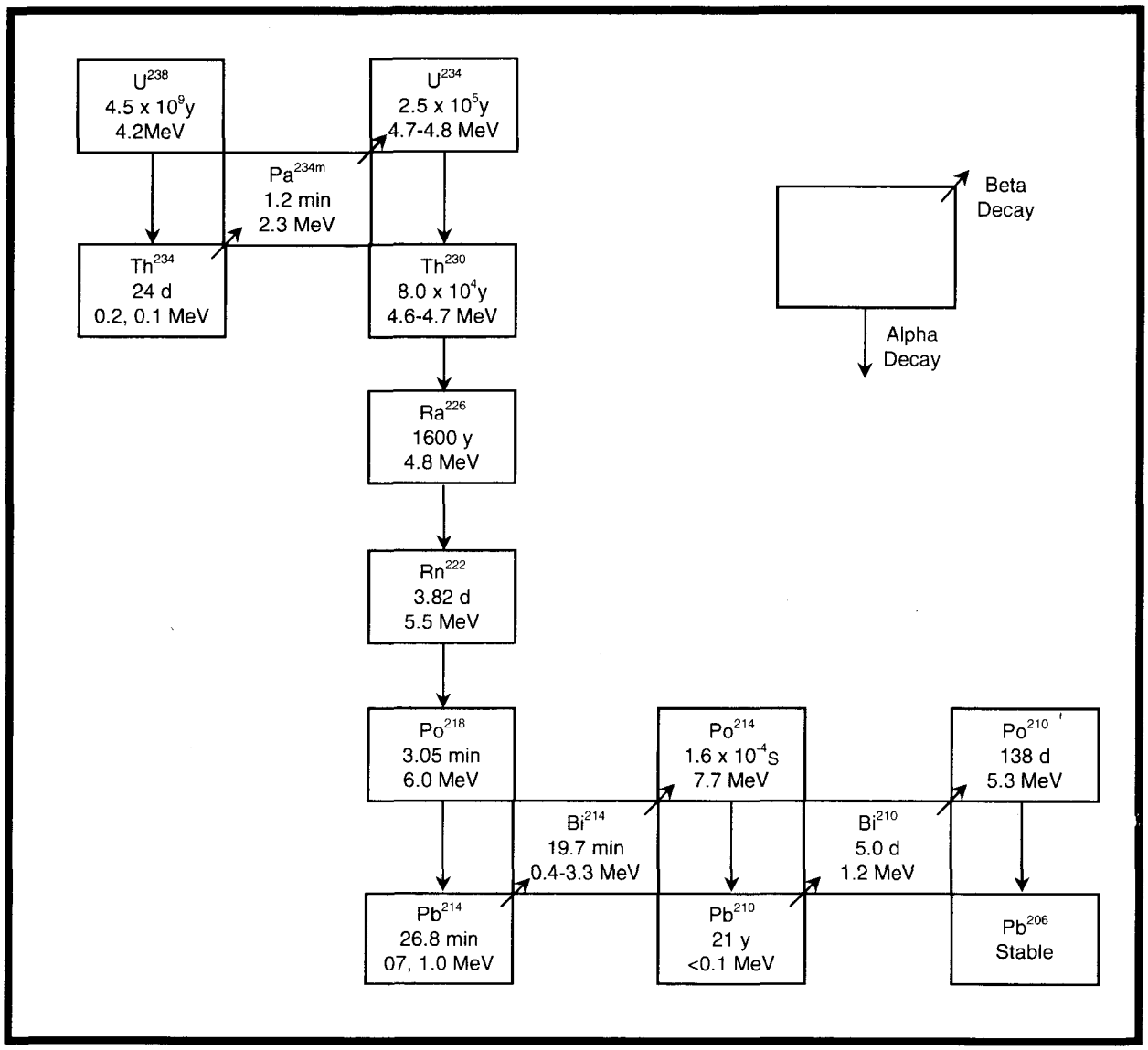


Exhibit B-2: Principal Decay Scheme of the Uranium Series

Each radioactive isotope has a specific rate of decay, known as its half-life, which is the time required for the isotope to decay to half of its original quantity. Carbon-14 has a half-life of 5,730 years, meaning that in that time, one gram of carbon-14 will become one-half gram of C-14 (the other one-half gram would have decayed to nitrogen-14 through beta decay of carbon-14 atoms). In an additional 5,730 years, the amount will be reduced to 0.25 grams of carbon-14 (with 0.75 grams having been transformed to nitrogen-14). Half-lives are unique to each radioactive isotope. Exhibit B-3 presents the half-lives and average radiation energies for alpha, beta and gamma radiation for some of the radionuclides found at Superfund sites.

		Average Radiation Energies (MeV/decay)[1]		
Radionuclide	**Half-Life**[2]	**Alpha**	**Beta**	**Gamma**
Am-241	4.32×10^{2}y	5.57×10^{0}	5.21×10^{-2}	3.24×10^{-2}
Am-243	7.38×10^{3}y	5.36×10^{0}	2.17×10^{-2}	5.61×10^{-2}
C-14	5.73×10^{3}y	--	4.95×10^{-2}	--
Co-60	5.27×10^{0}y	--	9.65×10^{-2}	2.50×10^{0}
Cs-134	2.06×10^{0}y	--	1.64×10^{-1}	1.55×10^{0}
Cs-135	2.30×10^{6}y	--	6.73×10^{-2}	--
Cs-137	3.00×10^{1}y	--	1.87×10^{-1}	--
H-3	1.23×10^{1}y	--	5.68×10^{-3}	--
K-40	1.28×10^{9}y	--	5.23×10^{-1}	1.56×10^{-1}
Pb-210	2.23×10^{1}y	--	3.80×10^{-2}	4.81×10^{-3}
Pu-238	8.77×10^{1}y	5.59×10^{0}	1.06×10^{-2}	1.81×10^{-3}
Pu-239	2.41×10^{4}y	5.24×10^{0}	6.74×10^{-3}	8.07×10^{-4}
Pu-240	6.54×10^{3}y	5.24×10^{0}	1.06×10^{-2}	1.73×10^{-3}
Pu-241	1.44×10^{1}y	1.22×10^{4}	5.25×10^{-3}	2.55×10^{-6}
Pu-242	3.76×10^{5}y	4.97×10^{0}	8.73×10^{-3}	1.44×10^{-3}
Ra-226	1.60×10^{3}y	4.86×10^{0}	3.59×10^{-3}	6.75×10^{-3}
Ra-228	5.75×10^{0}y	--	1.69×10^{-2}	4.14×10^{-9}
Sr-90	2.91×10^{1}y	--	1.96×10^{-1}	--
Tc-99	2.13×10^{5}y	--	1.01×10^{-1}	--
Th-230	7.70×10^{4}y	4.75×10^{0}	1.42×10^{-2}	1.55×10^{-3}
Th-232	1.41×10^{10}y	4.07×10^{0}	1.25×10^{-2}	1.33×10^{-3}
U-234	2.44×10^{5}y	4.84×10^{0}	1.32×10^{-2}	1.73×10^{-3}
U-235	7.04×10^{8}y	4.47×10^{0}	4.92×10^{-2}	1.56×10^{-1}
U-238	4.47×10^{9}y	4.26×10^{0}	1.00×10^{-2}	1.36×10^{-3}

Exhibit B-3: Radiological Characteristics of Selected Radionuclides Found at Superfund Sites[3]

---

[1] Computed as the sum of the products of the energies and yields of individual radiations.

[2] Half-life expressed in years (y).

[3] Source: *Principals for Limiting Exposure of the Public to Natural Sources of Radiation*, International Commission on Radiological Protection, 1983, ICRP Publication 39.

BASIC TERMS, TYPES AND UNITS OF RADIATION

Basic Terms

Activity

The quantity of a radioactive nuclide present at a particular time, expressed in terms of the mean rate of nuclear transformations The special name for the SI unit of activity (s-1) is Becquerel (Bq). The conventional unit is the curie (Ci). 1Ci = 3.7 x 1010 Bq.

Background Radiation

The radiation in man's natural environment, including cosmic rays and radiation (which may vary from location) from the naturally radioactive elements, both outside and inside the bodies of humans and animals. It is also called natural radiation.

Coulomb

The amount of electricity transported by a current of one ampere flowing for one second.

Decay Constant

The fraction of the amount of a radionuclide that undergoes transition per unit time. Lambda (λ) is the symbol for decay constant.

Dose

A general term denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified. If unqualified, it refers to absorbed dose.

Erg

The unit of energy in the centimeter–gram–second system of physical units, that is, one dyne-centimeter. One erg is equal to 10 -7 joule

Ion

Atomic particle, atom, or chemical radical bearing an electric charge, either negative or positive.

Ionization

The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

Ionizing radiation

Any radiation capable of removing electrons from atoms or molecules, thereby producing ions. Examples are alpha and beta particles.

Isotope

One of several nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore, in the mass number. Almost identical chemical properties exist between isotopes of a particular element. The use of this term as a synonym for nuclide is to be discouraged.

Non-ionizing radiation

Non-ionizing radiation is radiation without enough energy to remove tightly bound electrons from their orbits around atoms. Examples are microwaves and visible light.

Radiation

The emission and propagation of energy through space or through material in the form of electromagnetic waves or particles.

Radioactive Decay

The process by which a spontaneous change in nuclear state takes place. This process is accompanied by the emission of energy in various specific combinations of electromagnetic and corpuscular radiation and neutrinos.

Radioactivity

The property of certain nuclides of spontaneously emitting particles or gamma radiation during nuclear transformations.

Common Units of Radiation

Becquerel (Bq)

The SI unit of radioactivity, defined as the activity of a quantity of radioactive material in which one nucleus decays per second. It has units of s^{-1}.

Curie (Ci)

The curie is a unit used to measure a radioactivity. One curie is that quantity of a radioactive material that will have 37,000,000,000 transformations in 1 second. Often radioactivity is expressed in smaller units like: thousandths (mCi), millionths (uCi) or even billionths (nCi) of a curie. The relationship between becquerels and curies is: 3.7 X 1010 Bq in 1 curie [or 1 Bq = 27 pCi].

Rad (radiation absorbed dose)

The conventional unit for absorbed dose of ionizing radiation. One rad is defined as the absorption of 100 ergs per gram (0.01 J/kg) of material. 1 rad - 0.01 Gy. The rad unit can be used for any type of radiation absorbed in any material but does not describe the biological effect on that material.

Rem (roentgen equivalent man)

The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or millirem (mrem). To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

Roentgen

The roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and x rays, and only in air. One roentgen is equal to depositing 2.58 E-4 coulombs per kg of dry air. It is a measure of the ionizations of the molecules in a mass of air. The main advantage of this unit is that it is easy to measure directly, but it is limited because it is only for deposition in air, and only for gamma and x rays.

LIST OF ELEMENTS AND SYMBOLS

Actinium	Ac	Magnesium	Mg
Aluminum	Al	Manganese	Mn
Americium	Am	Mendelevium	Md
Antimony	Sb	Mercury	Hg
Argon	Ar	Molybdenum	Mo
Arsenic	As	Neodymium	Nd
Astatine	At	Neon	Ne
Barium	Ba	Neptunium	Np
Berkelium	Bk	Nickel	Ni
Beryllium	Be	Niobium	Nb
Bismuth	Bi	Nitrogen	N
Boron	B	Nobelium	No
Bromine	Br	Osmium	Os
Cadmium	Cd	Oxygen	O
Calcium	Ca	Palladium	Pd
Californium	Cf	Phosphorus	P
Carbon	C	Platinum	Pt
Cerium	Ce	Plutonium	Pu
Cesium	Cs	Polonium	Po
Chlorine	Cl	Potassium	K
Chromium	Cr	Praseodymium	Pr
Cobalt	Co	Promethium	Pm
Copper	Cu	Protactinium	Pa
Curium	Cm	Radium	Ra
Dysprosium	Dy	Radon	Rn
Einsteinium	Es	Rhenium	Re
Erbium	Er	Rhodium	Rh
Europium	Eu	Rubidium	Rb
Fermium	Fm	Ruthenium	Ru
Fluorine	F	Samarium	Sm
Francium	Fr	Scandium	Sc
Gadolinium	Gd	Selenium	Se
Gallium	Ga	Silicon	Si
Germanium	Ge	Silver	Ag
Gold	Au	Sodium	Na

Hafnium	Hf
Helium	He
Holmium	Ho
Hydrogen	H
Indium	In
Iodine	I
Iridium	Ir
Iron	Fe
Krypton	Kr
Lanthanum	La
Lawrencium	Lr
Lead	Pb
Lithium	Li
Lutetium	Lu
Strontium	Sr
Sulfur	S
Tantalum	Ta
Technetium	Tc
Tellurium	Te
Terbium	Tb
Thallium	Tl
Thorium	Th
Thulium	Tm
Tin	Sn
Titanium	Ti
Tungsten	W
Uranium	U
Vanadium	V
Xenon	Xe
Ytterbium	Yb
Yttrium	Y
Zinc	Zn
Zirconium	Zr

Sample Measurement Units, Activity and Mass

Introduction

Typically units of decay rate instead of mass are used to quantify the concentration of radioactive material in soil because the carcinogenic risks of exposure to soils contaminated with radioactive materials are related more to the decay rate of the material than to its mass. For example, one gram of ^{226}Ra has a decay rate (activity) of $3.7x10^{10}$ transformations per second (also referred to as disintegrations per second), while one gram of ^{137}Cs has a decay rate of $3.2x10^{12}$ transformations per second. Since it is the energy emitted by the radioactive material during radioactive decay and the frequency of the decay that is usually of public health concern, and generally not the chemical properties of the radioactive material, it is more meaningful for health assessment purposes to quantify radioactive material according to decay rate. In addition, radioactive materials are detected and quantified by the type of radiation emitted and number of disintegrations (per unit time), not by their unique chemistry, as is the case for non-radioactive material. For these reasons, the concentration of radioactive material in soil and water is typically expressed in units of decay rate, pCi/g and pCi/l.

When and How to Calculate Mass

Mass units provide insight and information into treatment selection, treatment compatibility, and treatment effiency, particularly for remedial actions involving mixed waste. For example, remediation goals expressed in mass are important for designing and evaluating treatment technologies such as soil separation, pump and treat, as well as subsurface barriers. Typically units for expressing mass in environmental media for soil and water are mg/kg for soil and mg/l for water. These mass units also can be expressed as parts per million (ppm) for soil and water, which is equivalent to mg/kg and mg/l. Soil activity, in pCi/g, may be converted to its mass equivalent of mg/kg, and Maximum Contaminant Levels (MCLs) for water activity in pCi/l may be converted to its mass equivalent mg/l by the following equations:

$$\text{Soil Mass} \quad (mg/kg) = 2.8 \times 10^{-12} \times A \times T_{1/2} \times \text{soil activity } (pCi/g)$$

$$MCL \quad (mg/l) = 2.8 \times 10^{-15} \times A \times T_{1/2} \times MCL\ (pCi/l)$$

Where 2.8×10^{-12} for soil or 2.8×10^{-15} for water is a conversion factor, A is the radionuclide atomic weight in g/mole, and $T_{1/2}$ is the radionuclide half-life in years. To put the relationship between mass (mg/kg) and activity (pCi/g) into perspective, examine the soil concentration in mg/kg corresponding to a soil activity of 1 pCi/g for a long-lived radionuclide such as ^{238}U and a relatively short-lived one such as ^{60}Co. ^{238}U has a half-life of $4.51 \times 10^{+9}$ years, so a 1 pCi/g of soil activity would be equivalent to a soil mass of 3 mg/kg. On the other hand, a soil activity of 1 pCi/g soil activity of ^{60}Co, which has a half-life of 5.26 years, is equivalent to about a soil mass of 1×10^{-9} mg/kg. Most radionuclides, which are a concern for site cleanups, have half-lives ranging from a few years to 10,000 years. Most activities are in fact less than 1 pCi/g so the equivalent masses in mg/kg values are even smaller. Therefore, at either soil levels or MCL levels, the masses of most radionuclides are extremely small values.

Background Information on Using Mass

One important issue associated with using mass to characterize the quantities of radioactive material in the environment is that many elements, such as uranium, have several isotopes of the same element. It is important to recognize that different isotopes will or may have different amounts or types of radioactivity. This will affect specific isotope radio-toxicity and potential risk. For example, if one were to perform atomic absorption analysis of a water sample, and it revealed the

presences of I mg/kg of uranium^{234}U, or ^{235}U, there would be no way of knowing how much uranium in the sample was^{238}U, or ^{234}U or ^{235}U, all of which are present in the environment naturally and due to anthropogenic activities. The potential public health and environmental impact of a given concentration of uranium in the environment will depend on the specific isotopes of uranium that are present, which could vary considerably depending on whether we are dealing with naturally occurring uranium or uranium that may have been enriched in ^{235}U as part of the uranium fuel cycle or as part of weapons production. It is also important to note that the same mass of each uranium isotope has significantly different levels of radioactivity. A mass of 1 mg/kg of ^{238}U (1 mg of ^{238}U in 1 kg of soil) has an activity of 0.33 pCi/g of ^{238}U. The same mass of ^{235}U (1 mg of ^{235}U in 1 kg of soil) has an activity of 2.1 pCi/g of ^{235}U and 1mg/kg of ^{234}U has an activity of 6,200 pCi/g of ^{234}U.

Also, many radioactive elements are present in the environment along with their stable counterpart. One example is potassium, which is naturally-occurring in the environment, ranging from 0.1 to 1% in limestone to 3.5% in granite. In addition, a typical 70 kg adult contains 130 g of potassium. A very small fraction (0.01%) of this potassium is the naturally-occurring radioactive isotope ^{40}K. If one were to measure the amount of ^{40}K in soil and assume that ^{40}K made up all of the elemental potassium, the mass of the elemental potassium would be underestimated by 10,000 fold.

The potential adverse effects of radioactive material are due to its disintegration rate. Measurement of the mass of a given element present (which usually includes all isotopes, stable and non stable isotopes of that element) may not accurately present the amount of radioactive isotope or isotopes of that given element are present. Therefore, its potential radio-toxicity and health risk may be greatly overestimated or underestimated.

Use of Mass in Remediation and Technology Selection

The measurement of the radioactivity present often will be a misrepresentation of the total mass of the given element and should not be used alone to calculate the treatment required for remediation technologies, since technologies are essentially chemical /physical. Doing so may underestimate the total mass of the given element and lead to errors in the amount of treatment or reactants required for remediation since technologies are chemically/physically based. For example, to design and implement a subsurface Permeable Reaction Wall for the uranium isotopes described above, it would be necessary to know the total mass of the uranium isotopes as well as the other aqueous reactive elements to calculate the equivalent amounts of sorption or precipitation reactants that would be required to remove or reduce the aqueous uranium species from contaminated groundwater (EPA 2000a & EPA 1999a). The same considerations would be necessary for other groundwater or water treatment technologies for dissolved concentrations of elements and their isotopic forms. For example in a pump and treat groundwater extraction system that utilizes ion exchange (chemical separation) or reverse osmosis (physical separation), chemical mass measurements would be used to determine the amount and type of reactants materials, exchange capacity and effectiveness (EPA 1996). Much the same can be said for mobility limiting or mobility reduction technologies such as chemical solidification /stabilization treatability studies or treatments (EPA, 2000b). Also, mass measurements are important in the determination of partition coefficients, K_d values that are essential in fate and transport, risk assessment modeling, and remediation calculation. K_d values are expressed in mass units for the inorganic element and isotopes (EPA 1999b). Partition coefficients, K_d values, are the same value for all forms of the element and isotopes.

In summary, given that risk of exposure is the basis for remedial actions, mass measurements are often required for determinng, designing and selecting a remediation technology. This contrasts with the need for radiation specific isotopic measurements required in risk and exposure analysis. Users should note the different applications and perspectives with their corresponding measurements units of mass and activity.

References

U.S. EPA. 1996. *Technology Screening Guide for Radioactively-Contaminated Site.* EPA-402-R-96/017. Office of Radiation and Indoor Air, Washington, DC.

U.S. EPA. 2000. *Field Demonstration of Permeable Reactive Barriers to Remove Dissolved Uranium From Groundwater, Fry Canyon, Utah, September 1997 through Septermber 1998, Interim Report.* EPA 402-C-00-001. Office of Radiation and Indoor Air, Washington, DC.

U.S. EPA. 1996b. *Understanding Variation inPartition coefficient, K_d, Values. Volume 1 & 2. EPA-402-R-99-004A PB2000 108438 and EPA-402-R-99-004A PB2000 108439.* Office of Radiation and Indoor Air, Washington, DC.

U.S. EPA. 2000a. *In Situ Permeable Reactive Barriers: Application and Deployment.* Training Manual. EPA-542-B-00-001/ Office of Solid Waste and Emergency Response, Washington, DC.

U.S. EPA. 2000b. *Testing Stabilzation/Solidification Processes for Mixed Wasste.* EPA-402-R-00-008. Office of Radiation and Indoor Air, Washington, DC.

Frequent Technical Questions

Common technical questions about MARSSIM fall into these topic areas:

- The DCGL (Derived Concentration Guidance Level)
- The MDC (Minimum Detectable Concentration)
- The LBGR (Lower Bound of the Grey Region)
- Double Sampling
- Size of the Survey Unit

Other Questions/Comments

Common general questions:
Frequently Asked Questions page.
Other questions or comments:
Kathryn Snead
202-343-9228
snead.kathryn@epa.gov

MARSSIM

Main Page
Frequent General Questions
Recent Additions
Related Links
MARSSIM Users
Obtain Tools
Comments
Training
Frequent Technical Questions
MARSSIM Workgroup
Workgroup Meetings
About the Workgroup

Questions

The DCGL (Derived Concentration Guidance Level)

- What is a Derived Concentration Guideline Level (DCGL)?
- How can I obtain DCGLs?
- How can I make my survey design more efficient?
- How does the DCGL affect the survey design?

The MDC (Minimum Detectable Concentration)

- What is the Minimum Detectable Concentration (MDC)?
- How is the MDC calculated?
- What is a scan MDC?
- What is the major consequence of missing an elevated area?

The LBGR (Lower Bound of the Grey Region)

- What is the LBGR?
- Why do I need an LBGR?
- How do I choose the LBGR?
- What is the relative shift?
- What value should I use for the LBGR, if there is no prior survey information?
- When should I choose a value of the LBGR?

Double Sampling

What is double sampling?
Why would I want to perform double sampling?
Does MARSSIM allow double sampling?

Size of the Survey Unit

What sizes does MARSSIM recommedn for survey units?
Can I use a different survey unit size than the examples in MARSSIM?
What is the relationship between survey unit size and the establishment of the DCGLW?
What is the effect on the DCGLW when I decrease or increase the survey unit size?

Answers

The DCGL (Derived Concentration Guideline Level)

What is a Derived Concentration Guideline Level (DCGL)?

The Derived Concentration Guideline Level (DCGL) is a radionuclide-specific surface or volume residual radioactivity level that is related to a concentration or dose or risk criterion. The regulator usually determines this criterion.

The $DCGL_W$ is a reference criterion, or radioactivity level for residual radioactivity evenly distributed over a large area.

The $DCGL_{EMC}$ ("EMC" stands for elevated measurement exposure) is used when small areas of elevated radioactivity exist within larger areas.

Chapter 2: Overview of the Radiation Survey and Site Investigation Process (PDF) (40 pp, 408K [about pdf format])(Section 2.2)
Glossary (PDF) (24 pp, 308K [about pdf format])

How can I obtain DCGLs?

Methods for deriving DCGLs are outside the scope of MARSSIM. Consult the appropriate regulatory agency personnel or documents for methods used to develop DCGL values.

Appendix L: Regional Radiation Program Managers (PDF) (8 pp, 51K [about pdf format])

How does the DCGL affect the survey design?

The answer depends upon a number of factors. In the most general terms, with all other factors being equal, the number of measurements varies inversely with the DCGL.

In reality, a change in the DCGL reflects a change in the assumptions used to translate dose or risk into concentration. This could affect the survey design in several ways. For example, changing the area of radioactivity in the exposure pathway model would change the size of survey units specified in the survey design. In another example, changes in the depth of radioactivity assumed by the model would change the sample collection procedures and scan

sensitivity required for the final status survey design. In these cases it is difficult to predict what exact affect the DCGL will have on the survey design.

How can I make my survey design more efficient?

Controlling the number of measurements is the key to efficient surveys, which make the best use of limited resources. MARSSIM allows you to examine the factors that drive the number of measurements required:

- DCGL
- radionuclide concentration variability in the survey unit and background
- tolerable decision error rates
- identifying elevated areas.

Once you identify the reason the survey design recommends a specific number of measurements, you can determine what, if any, changes to the survey design are appropriate.

Chapter 5:Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])

The MDC (Minimum Detectable Concentration)

What is the Minimum Detectable Concentration (MDC)?

The MDC is the net concentration that has a specified chance of being detected. It is an estimate of the detection capability of a measuring protocol and is calculated before measurements are taken.

The detection limit is the lowest net response level, in counts, that you expect to be see with a fixed level of certainty, customarily 95%. The MDC is the detection limit expressed as an activity concentration. If the activity concentration in a sample is equal to the MDC, then there is a 95% chance that radioactive material in the sample will be detected.

Chapter 6: Field Measurement Methods and Instrumentation (PDF)(66 pp, 641K [about pdf format]) (Section 6.7.1)

How is the MDC calculated?

You can calculate the MDC for an instrument by considering the background counts during a typical measurement, total detection efficiency, conversion factors, and the probe area.

Variability in the calculated MDC reflects natural variability in the detection efficiency and conversion factors. This variability may or may not be significant. For the MDC to be applicable, the sample or field measurement conditions must match the conditions under which the background was measured.

Chapter 6: Field Measurement Methods and Instrumentation (PDF) (66 pp, 641K [about pdf format]) (Section 6.7.1)

390003

What is a scan MDC?

The concept of the scan MDC is especially important in MARSSIM. A scan MDC is an MDC calculated for an instrument that takes continuous or "scanning" measurements. A scanning instrument can often take more measurements for less cost and in less time than a non-scanning instrument. However, it is important that the scan MDC obtained by the scanning procedures used will actually detect the required DCGL in the field.

If the scan MDC is adequate to detect the $DCGL_{EMC}$, it can be used to greatly reduce or eliminate the possibility of missing an area of elevated concentration.

What is the major consequence of missing an elevated area?

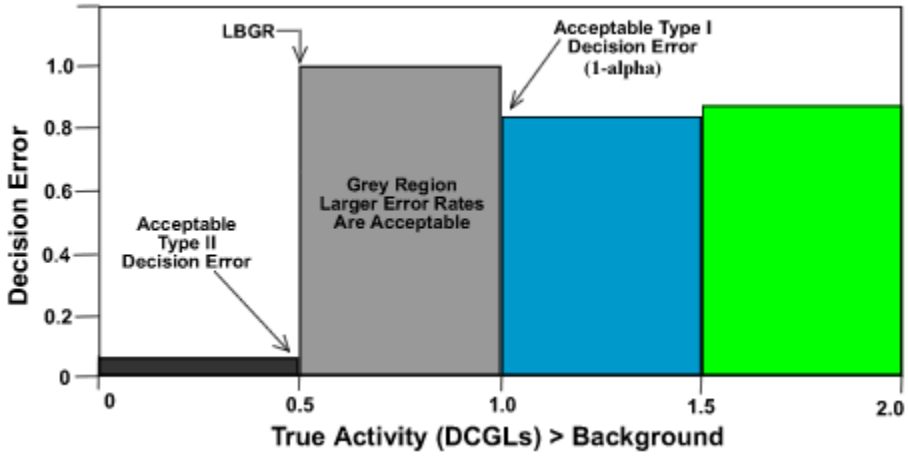
Missing an elevated measurement area may cause release of a survey unit that exceeds the dose criteria.

The LBGR (Lower Bound of the Grey Region)

What is the LBGR?

The LBGR (Lower Bound of the Grey Region) is a concentration. It is less than the $DCGL_W$ and is chosen to be easily distinguishable from the $DCGL_W$. You apply a statistical test to the data to determine whether the true concentration in the survey unit is above the $DCGL_W$ or below the LBGR. You are more likely to make an inaccurate decision if the true concentration of the survey unit is between the LBGR and the $DCGL_W$. Thus, it is called the "grey region" because in that case, the decision is usually neither "black" nor "white." See the figure below for a graphic depiction of the LBGR.

An Example Decision Rule for the Final Status Survey



Chapter 5: Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])
Appendix D: The Planning Phase of the Data Life Cycle (PDF (29 pp, 280K [about pdf format])

Why do I need an LBGR?

You need the LBGR to calculate the number of data points, N, which is used to test whether the survey unit concentration is less than the $DCGL_W$. You must set a value for the LBGR to

390004

calculate the shift, (shift = $DCGL_W$ - LBGR = Δ). The shift is then used to calculate the relative shift, Δ / σ, which is an intermediate step necessary to calculate N.

What is the relative shift?
Chapter 5: Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])
Chapter D: The Planning Phase of the Data Life Cycle (PDF) (29 pp, 280K [about pdf format])

How do I choose the LBGR?

Choosing the LBGR is part of an iterative process used to determine the number of data points, N, needed. You can set the LBGR at the median residual radioactivity concentration believed to be remaining in the survey unit. If the true, but unknown, concentration in the survey unit is in the grey region, you will have difficulty in determining if the survey unit concentration is less than the $DCGL_W$. You should take into account the following when choosing the LBGR:

- variation of the concentrations in the survey unit (determined from prior surveys of the survey unit)
- variation in the measurements due to instrumentation at the candidate values for the LBGR
- possibility a survey unit could fail even though its average concentration is, in fact, less that the $DCGL_W$
- costs of measurements at the sensitivities needed to measure the candidate values for the LBGR

You can optimize the trade-offs between increased instrument sensitivity, costs, and the number of data points needed by setting the LBGR so that you get a relative shift greater than one and less than three.

What is the relative shift?
What value should I use for the LBGR, if there is no prior survey information?
Chapter 5: Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])
Chapter D: The Planning Phase of the Data Life Cycle(PDF) (29 pp, 280K [about pdf format])

What is the relative shift?

The relative shift expresses the width of the grey region, or shift, Δ, in terms of the number of standard deviations of the measurement data, σ, and is designated as ($DCGL_W$ - LBGR/ σ) or Δ / σ . The degree of difficulty in distinguishing the LBGR from the $DCGL_W$ depends on the variability of the data as well as the size of the shift, . The smaller the relative shift, the larger the number of samples. The number of samples increases rapidly with only small decreases in the value of the relative shift when the value of the relative shift is below one.

Chapter 5: Survey Planning and Design(PDF) (55 pp, 735K [about pdf format])
Appendix D: The Planning Phase of the Data Life Cycle (PDF) (29 pp, 280K [about pdf format])

390005

What value should I use for the LBGR, if there is no prior survey information?

When no other information is available, MARSSIM suggests a default value for the LBGR equal to ½ the $DCGL_W$. Then you can begin the iterative process described in How do I choose the LBGR?

What is the relative shift?
Chapter 5: Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])
Chapter D: The Planning Phase of the Data Life Cycle(PDF) (29 pp, 280K [about pdf format])

When should I choose a value for the LBGR?

You should choose a preliminary value of the LBGR before remediation and a final value of the LBGR as you complete the Final Status Survey design. There are a number of factors that determine the final value of the LBGR. In some cases, you will want to remediate to concentrations sufficiently below the $DCGL_W$, so you can demonstrate the survey unit meets the release criterion.

How do I choose the LBGR?
Chapter 5: Survey Planning and Design (PDF) (55 pp, 735K [about pdf format])
Chapter D: The Planning Phase of the Data Life Cycle (PDF) (29 pp, 280K [about pdf format])

Double Sampling

What is double sampling?

Double sampling is taking a second set of samples in a one-stage survey, because the retrospective power of the test did not meet design objectives. At the same time, double sampling causes the Type I error rate to exceed the rate specified for the one-stage survey.

Before the initial round of sampling takes place, DQOs should mention any allowances for double sampling and be approved by the appropriate regulators. During the DQO process, double sampling could be considered as an option to setting the Type I error rates.

Why would I want to perform double sampling?

When the retrospective power of a set of samples is below the required design objectives, double sampling can raise it. Insufficient retrospective power can occur for a number of reasons, most commonly because:

- The spatial variability in residual radioactivity concentrations is larger than anticipated.
- Samples were lost, did not pass analytical QA/QC, or were otherwise unavailable for inclusion in the analysis.

Does MARSSIM allow double sampling?

MARSSIM discourages double sampling. The DQO process, which MARSSIM uses, explicitly sets objectives for both the Type II error rate and the retrospective power during the design process. Adequate initial sampling to achieve the desired power makes decisions based on the data more objective and defensible. A better solution to the issue of double sampling is to plan for data collection in two stages, and design the final status survey accordingly.

If your regulator allows double sampling, it should be decided upon during the DQO process. You should both agree upon the number of samples allowed in the second set of samples, because the Type I error rate could be as much as double the error rate for a single set of samples.

Class 2 or Class 3 survey units are not appropriate for double sampling. Concentrations in these survey units should not exceed the $DCGL_W$, and should always pass with the first set of samples. The need for a second set of samples in Class 2 or Class 3 survey units raises the issue of misclassification. Double sampling is also generally not appropriate for Class 1 survey units having confirmed areas of elevated activity, or "hot spots."

Size of the Survey Unit

What sizes does MARSSIM recommend for survey units?

The survey unit sizes in MARSSIM are not intended to be prescriptive. However, MARSSIM does offer one possible set of survey unit sizes, **primarily as an example**. For Class 1 survey units, MARSSIM suggests survey unit sizes of 100 m^2 for structures and 2,000 m^2 for land areas. For Class 2 survey units, MARSSIM suggests survey unit sizes between 100 and 1,000 m^2 for structures, and between 2,000 and 10,000 m^2 for land areas. However, these survey unit sizes are not intended to be prescriptive. For Class 3 survey units, MARSSIM does not suggest a limit for either structure or land areas. Section 4.6 of MARSSIM recommends limiting survey units based on classification, exposure pathway modeling assumptions, and site-specific conditions.

Chapter 4: Preliminary Survey Considerations (PDF) (39 pp, 469K [about pdf format])
(Section 4.6)

Can I use a different size survey unit than the example in MARSSIM?

Yes. The survey unit size should correspond to the model assumptions used to establish the $DCGL_W$ for the survey unit. As always, it is important to document the rationale for the assumptions and to consult with your regulator.

What is the relationship between survey unit size and the establishment of the DCGLW?

If the $DCGL_W$ was derived by environmental pathway modeling, then as the survey unit size changes in the model, the $DCGL_W$ may change too. Several factors affect this relationship, including the radionuclides of concern, the potential exposure pathways, and the uncertainties inherent in the model. Therefore, when considering changing the survey unit size, it is best to work with an experienced environmental pathway modeler to fully account for all the complexities inherent at your site. These changes may or may not affect the survey design. These changes may or may not affect the survey design. It is important to talk with your regulator to determine if the resulting changes have significant impact on the $DCGL_W$ previously agreed upon with your regulator.

What is the effect on the DCGLW when I decrease or increase the survey unit size?

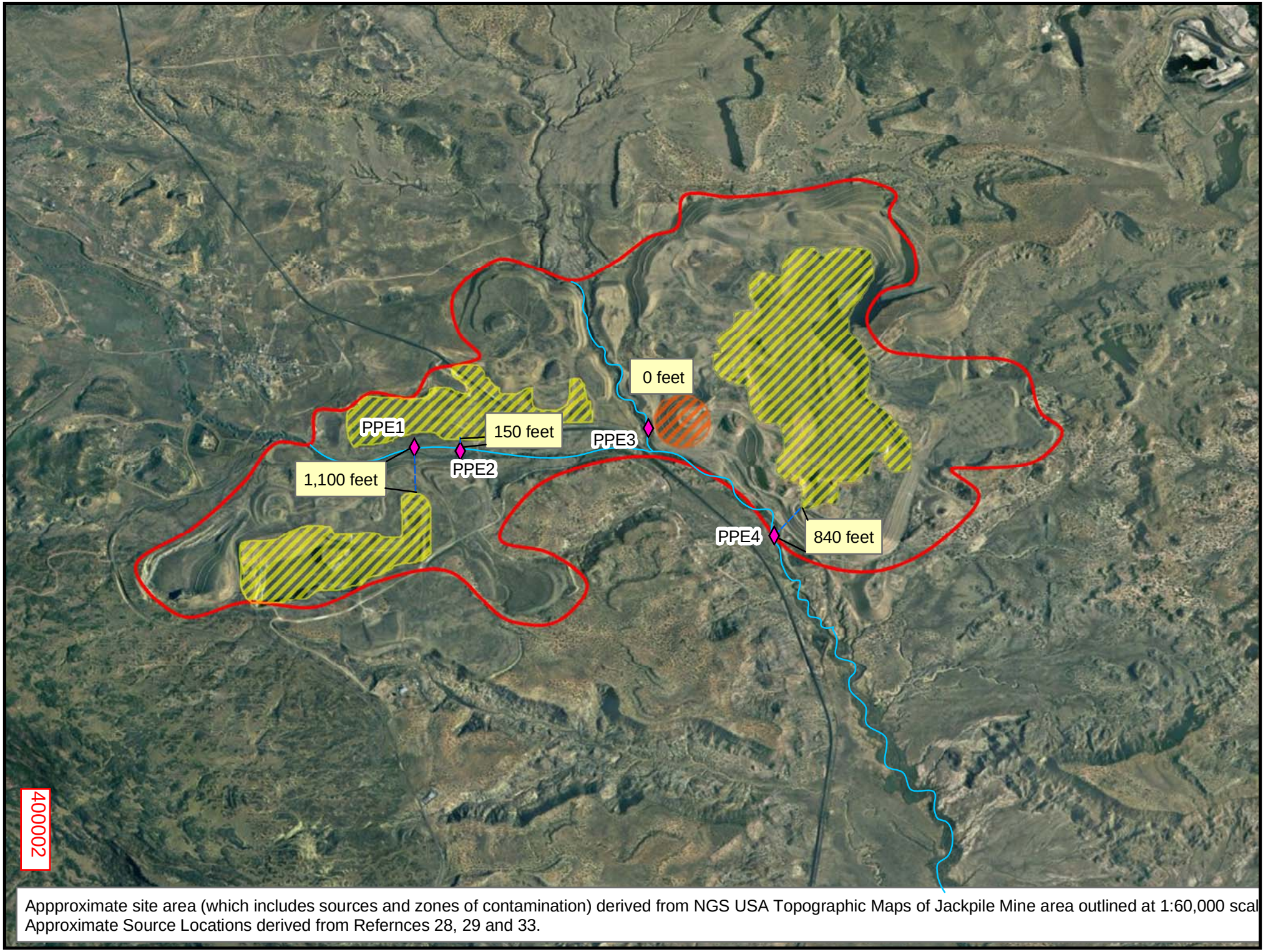
In general, when you use a survey unit size smaller than the modeled survey unit size, it is possible that you could take more measurements than necessary using the same the $DCGL_W$. However, if the size is not significantly smaller, it will usually be simpler to make the number

of measurements calculated, rather than re-deriving a new $DCGL_W$ with new modeling. If the survey unit is larger than what was modeled, then you should divide the survey unit into sizes that conform to the model. Alternatively, you may re-calculate the $DCGL_W$ to conform with the larger survey unit size by inserting the larger survey unit size into the model. In either case, approval from the regulator is recommended before making changes to survey unit sizes.

PROJECT NOTE

TO:	Project File
SUBJECT:	Jackpile-Paguate Uranium Mine Paguate, Cibola County, New Mexico CERCLIS ID No. NMN00607033
TASK DESCRIPTION:	Overland Flow Distance Measurements
W.O. NO.:	20406.012.019.0514.01
DATE:	October 17, 2011
PREPARED BY:	Michelle Brown, Weston Solutions, Inc.
TITLE:	Senior Project Leader

WESTON utilized the Environmental Systems Research Institute (ESRI) ArcView GIS software version 9.3.1 to measure the overland distance between the identified sources 1 and 2 to the PPEs (see attached Figure).



Appproximate site area (which includes sources and zones of contamination) derived from NGS USA Topographic Maps of Jackpile Mine area outlined at 1:60,000 scal
Approximate Source Locations derived from Refernces 28, 29 and 33.

Conversation with tribal member about consuming fish from the Rio Paguate, below Mesita Dam

On Friday October 14, 2011 I, Frank A. Ortiz Cerno Natural Resources Specialist, engaged in a conversation with a tribal member from the village of Mesita by the name of Stacey Carr. I asked Mr. Carr if he knew anyone who, at any time, may have consumed any species of fish from the Rio Paguate between the Jackpile Mine and the Mesita Dam. Mr. Carr then stated that he and his girlfriend (not named) did consume fish from the ponds just below (downstream) Mesita Dam on many occasions.

Frank A. Ortiz Cerno

October 24, 2011